State of Rhode Island and Providence Plantations.

TWENTY-NINTH ANNUAL REPORT

OF THE

COMMISSIONERS OF INLAND FISHERIES,

MADE TO THE

GENERAL ASSEMBLY

AT ITS

JANUARY SESSION, 1899.

PROVIDENCE, R. I.
E. L. FREEMAN & SONS, PRINTERS TO THE STATE.
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COMMISSIONERS OF INLAND FISHERIES OF RHODE ISLAND.

J. M. K. SOUTHWICK, *President*	Newport, R. I.
HENRY T. ROOT, *Treasurer*	Providence, R. I.
WM. P. MORTON, *Secretary*	P. O. Box 966, Providence, R. I.
CHAS. W. WILLARD	Westerly, R. I.
ADELBERT D. ROBERTS	P. O. Box 264, Woonsocket, R. I.
HERMON C. BUMPUS, Ph. D.	Brown University.

REPORT.

To the Honorable the General Assembly of the State of Rhode Island and Providence Plantations, its January Session, 1899:

The Commissioners of Inland Fisheries herewith present their annual report for the year 1898:

The appropriation, which was made by your honorable body, has enabled the Commissioners of Inland Fisheries to arrange their affairs in a much more satisfactory manner than heretofore, and to accomplish far more for the fishery industries of the State than during any previous year.

The problems undertaken by the Commission have been as follows:

First. The stocking of our ponds and streams with suitable fresh-water fish, through the distribution of eggs and fry.

Second. The collection of definite data respecting the times of arrival and departure of various food fish, and the preparation of statistics of exportation.

Third. The determination of the breeding periods of native marine animals.

Fourth. The location of fish traps and other appliances for the capture of fish.

Fifth. The physical and biological examination of the waters of the bay, and the preparation of a record of the present physical and biological conditions.

Sixth. The investigation of the plague which destroyed multitudes of fish and crustacea during the fall of 1898.

Seventh. The continuation of the observations begun in 1897 on the life-habits of the starfish.

Eighth. A survey of the waters of the bay and of the waters immediately off shore, for the purpose of determining the distribution of the starfish.

Ninth. A study of the life-habits of the clam, and an investigation of the present depleted conditions of the clam beds.

Tenth. The preparation of a relief map of Narragansett Bay.

Eleventh. An examination into the feasibility and practicability of artificial lobster culture.

Twelfth. The extension of the commercial fisheries of the State, through the discovery of new localities for food fish.

Thirteenth. Improvements in the methods of preparing fish for shipment.

How successful the Commission have been in the prosecution of their work will appear in the sequel under appropriate captions.

The receipts and disbursements of the Commission have been as follows:

State of Rhode Island in Account with Commissioners of Inland Fisheries.

1897.	Dr.	
Dec. 31.	To balance due Commissioners	$322 85
1898.		
Sept. 26.	To paid for 20,000 yearling trout	678 80
Dec. 31.	" " investigating star-fish, flat-fish, clam, and lobster	1,583 11
	" " expenses of Commissioners	635 35
	" " skiff	20 00
	" " printing, advertising, postage	34 72
		$3,274 83
1898.	Cr.	
Jan. 6.	By cash of State Treasurer	$322 85
April 2.	"	613 58
July 14.	"	15 55
31.	"	26 33
31.	"	100 00
Aug. 31.	"	164 89
31.	"	72 55

1898.		
Aug. 31.	By cash of State Treasurer	22 34
31.	"	464 94
Sept. 26.	"	600 00
Oct. 31.	"	212 22
Dec. 23.	"	69 92
31.	"	123 65
31.	"	50 00
31.	"	47 99
31.	"	28 62
31.	"	24 00
31.	"	266 10
31.	"	11 80
	Balance due Commissioners	37 50
		$3,274 83

J. M. K. SOUTHWICK,
HENRY T. ROOT,
CHAS. W. WILLARD,
WM. P. MORTON,
ADELBERT S. ROBERTS,
HERMON C. BUMPUS,

Commissioners of Inland Fisheries.

I. *The Stocking of our Ponds and Streams with Suitable Fresh-Water Fish, Through the Distribution of Eggs and Fry.*

During the past year the Commissioners have purchased twenty thousand yearling trout, and with the generous assistance of many fishermen have distributed them in various portions of the State.

BLACK BASS.

Large- and small-mouthed black bass have been placed in various ponds and rivers during the past season. Some very good catches of large fish have been reported. The United States Commission has kindly contributed five hundred large-mouthed black bass, which have been placed in the preserve set apart for the purpose of propagating this species, near Westerly.

LAND-LOCKED SALMON.

Three thousand fry were liberated in Mill Brook, May 9, 1898.

II. *The Collection of Definite Data Respecting the Times of Arrival and Departure of Various Food Fish, and the Preparation of Statistics of Exportation.*

For this purpose blank forms were distributed to the shore fishermen early in the summer, and the data thus obtained will be of practical assistance in the future work of the Commission.

An examination of the following table will show a most gratifying increase in the shipments by freight and express from Newport. Large quantities of fish are carried directly to the New York markets by those owning the larger "off-shore" traps, and many fish are also sent to New York and other market centres from Wickford and East Greenwich.

Shipment of Fish and Lobsters by Regular Lines of Freight Transportation from Newport, for the Years 1897 and 1898.

	Fish. Bbls. 1897.	Fish. Bbls. 1898.	Lobsters. Bbls. 1897.	Lobsters. Bbls. 1898.	Swordfish. Number. 1897.	Swordfish. Number. 1898.
January	270	518	17	11	..	..
February	489	509	..	..	..	..
March	46	112	1	1	..	..
April	204	475	62	38	..	..
May	7,670	11,583	225	219	..	..
June	6,154	8,668	452	212	..	..
July	1,610	3,144	638	432	44	14
August	1,664	3,378	380	213	1	7
September	3,112	2,351	170	25	..	1
October	2,557	2,441	15	4	..	..
November	1,135	648	19	5	..	52
December	147	235	60	13	..	..
Total	25,058	34,065	2,039	1,163	45	74

Total of fish and lobsters, 1897 ; 27,097 barrels.

Total of fish and lobsters, 1898 ; 35,228 barrels.

To the above shipments by freight may be added the following:

	Fish.	Lobsters.
Shipments from Newport by express	4,229	2,560
Total shipment	38,294	3,723 = 42,017 bbls.

The following is a tabulated statement of the relative quantities of fish shipped by *freight* from Newport over the Old Colony lines for the past thirteen years. It will be noticed that the shipment for 1898 is considerably greater than for any previous year, and is more than 50 per cent. greater than for 1897.

Table of Shipments by Old Colony Lines.

	Fish. Bbls.	Lobsters. Bbls.	Total.
1886			17,434
1887	16,657	834	17,491
1888	15,033	1,161	16,194
1889	19,306	2,047	21,353
1890	8,933	2,650	11,583
1891	18,032	2,204	20,236
1892	26,832	2,123	28,955
1893	24,452	1,399	25,851
1894	17,769	2,392	21,161
1895	24,622	2,119	26,741
1896	20,425	1,728	22,153
1897	20,900	1,959	22,859
1898	34,065	1,163	35,228

Fresh fish have been shipped direct from Newport to the following cities:

Albany, N. Y.,
Amsterdam, N. Y.,
Boston, Mass.,
Brockton, Mass.,
Buffalo, N. Y.,
Chicago, Ill.,
Dayton, Ohio,
Detroit, Mich.,
Dighton, Mass.,
Fall River, Mass.,
Ft. Edward, N. Y.,
Grand Rapids, Mich.,
Ithaca, N. Y.,
Jamestown, N. Y.,
Kansas City, Mo.,
Middletown, N. Y.,
New York, N. Y.,
Newburg, N. Y.,
New Bedford, Mass.,
Olean, N. Y.,
Poughkeepsie, N. Y.,
Providence, R. I.,
Riverside, R. I.,
Rome, N. Y.,
St. Louis, Mo.,
Saratoga, N. Y.,
Schenectady, N. Y.,
Tiverton, R. I.,
Troy, N. Y.,
Taunton, Mass.,
Warren, R. I.

III. *The Determination of the Breeding Periods of Native Marine Animals.*

Inasmuch as the movements of fish are largely controlled by the food supply, and the food supply is the direct consequent of the reproductive activity of the lower animals, it is essential that the Commission should have data relative to the breeding habits of both fish and the lower marine animals. The data collected during the past year has been published in "Science," where it is available for reference, and hence it seems unnecessary to publish it again in this report.

IV. *The Location of Fish Traps and Other Instruments for the Capture of Fish.*

The statutes of Rhode Island provide that the Commission "shall from time to time examine all the weirs, traps, and other contrivances, with the view of carrying out such regulations as are most beneficial to the people of the State." At the beginning of the present year the State had no information as to the number, location, or ownership of fish traps, and was consequently unadvised respecting the extent to which market fishing was carried on within its borders. Assisted by the boats of the United States Fish Commission and of the Marine Biological Laboratory, the Commissioners have visited all the fish traps, and while they have found the number to be large (115), they have found them controlled by an exceptionally intelligent class of men, well informed respecting the movements of marketable fish. The equipment and maintenance of these appliances represents the investment of considerable capital and the employment of a large number of men. A large proportion of the fish captured are consumed beyond the limits of the State, and the list of cities (section II) to which shipments are directly made indicates very clearly the reputation which the State must enjoy as a fisheries centre. It is un-

necessary to argue that large sums of money are brought into the State through the activities of those immediately interested in this industry.

Although the Commission is not in possession of facts respecting the influence which the great sea traps, temporarily located in the deeper water off the mouth of the bay, may have upon the fishes within the limits of the bay, it is almost the universal opinion among those who are handling large quantities of fish that the capture during the past year has been of much more than average value. This is the more interesting since serious complaints of damage wrought to the industry by wholesale methods of capture have been infrequent. Although the "twine" destroys thousands of barrels of fish which never even reach the market, and extensive "pounding" leads to the destruction of enormous numbers of enclosed fish, there is, at the present time, no other adequate way of capturing and of retaining certain fish until the market is in such a condition as to make their sale profitable. There is no question but that the sea traps are so efficient as instruments of capture that they frequently defeat their own purposes through capturing such enormous quantities of fish that the market becomes overstocked. During the past season, as heretofore, fish from these outside traps have not only been shipped from Newport over the regular lines of transportation, but some of the larger concerns have combined and carried their own fish to New York.

Scup are the principal fish captured off shore, and often the nets contain practically nothing else. Inasmuch as scup is one of the most popular food fish, and since it appears quite impossible for it to find a market when most abundant, it would seem that some plan of canning the scup would develop an industry, in the southern portion of the State, which might yield considerable revenue. It will be the purpose of the Commission the coming year to examine into the practicability and feasibility of preserving these fish.

The traps within the bay are often set as early as March, when

alewives, or buckies, are captured. Mr. Lewis, on the 17th of last March, caught seventeen hundred. During the early spring flat-fish are abundantly taken. The spring squeteague arrive about the first of June, when they are small but are said to bear spawn. The regular run of squeteague extends over about four weeks, from early in June to early in July. The fish have been very abundant during the past season, fifty barrels often being taken from a single trap at one haul. Sometimes the squeteague are so eager in their pursuit for young herring that they swarm into the shallow water in almost countless numbers, when they may be picked up with the hand and thrown upon the beach. Mr. Lewis tells me that he saw such a school last summer near Sanderstown, and that he waded into the water and captured sixty-three fish. The squeteague of late years has become a very popular food and game fish, and, although it does not endure protracted icing, an increasing number are finding their way to the larger centres of consumption. It appears on the bills of fare of many resorts as "blue-fish," and, although inferior in keeping qualities and in flavor, its abundance has given it a place among the marketable food-fish which the more or less uncertain blue-fish does not enjoy. The fishermen, moreover, look with increasing favor upon the arrival of the squeteague, for when it comes it comes to stay, and it does not drive away other fish. Scup may be taken in the traps, even at the head of the bay, Bristol, and East Greenwich. On the 3d of July seventy-five barrels were turned out of traps, near Wickford, as valueless. The tautog is taken in the traps in the spring and fall, although during the summer it is generally caught with hook and line.

A year ago the cod was so abundant in the traps around Sakonnet, Newport, and Point Judith that the nets became seriously damaged, and the market became overstocked. Some idea of their abundance may be gathered from the statement that on one day four men in a catboat caught eleven hundred and seventy. During the past fall the cod has not been sufficiently abundant to ruin its market.

In the spring of 1898 (April and May) many small cod, weighing about three pounds, were caught in the traps near Wickford. The appearance of these young cod, in considerable numbers and in localities where they have been heretofore unknown, is generally explained by the fishermen as an immediate result of the methods of artificial propagation which have been carried on at the Woods Hole Station. The millions of cod fry that have been liberated near our shore must have materially affected the fish fauna. Mr. F. H. Hoar caught near Bristol a large "racer cod" weighing about five pounds. Old fishermen in this portion of the bay consider this capture noteworthy, since they do not remember of ever having caught cod in this locality. It would seem possible that with increased facilities for artificial propagation even the upper waters of the bay may yield an abundance of what are ordinarily considered to be deep-water food-fish.

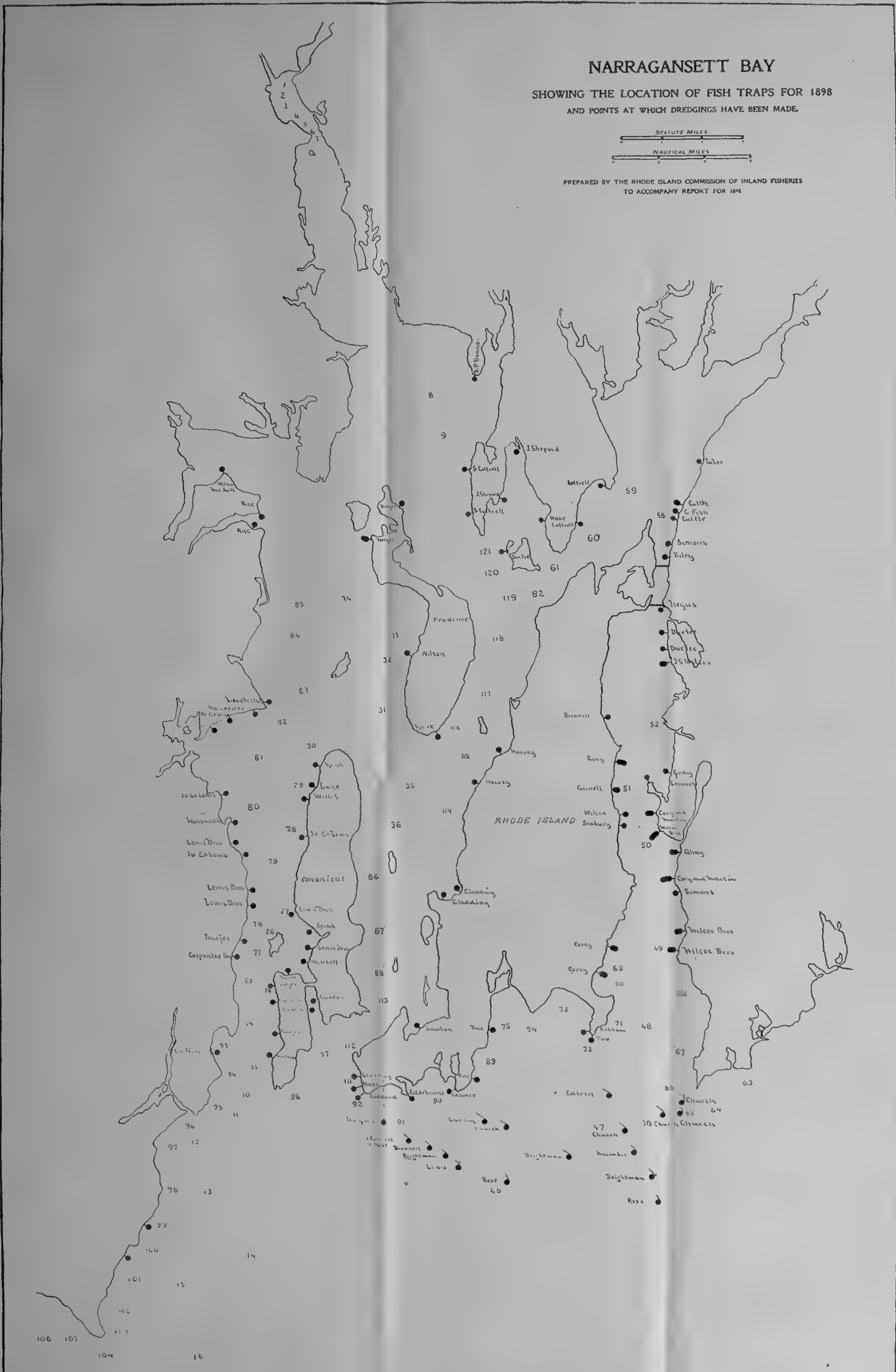
A list of the principal owners of fish traps is herewith given, together with the localities in which the traps are set:

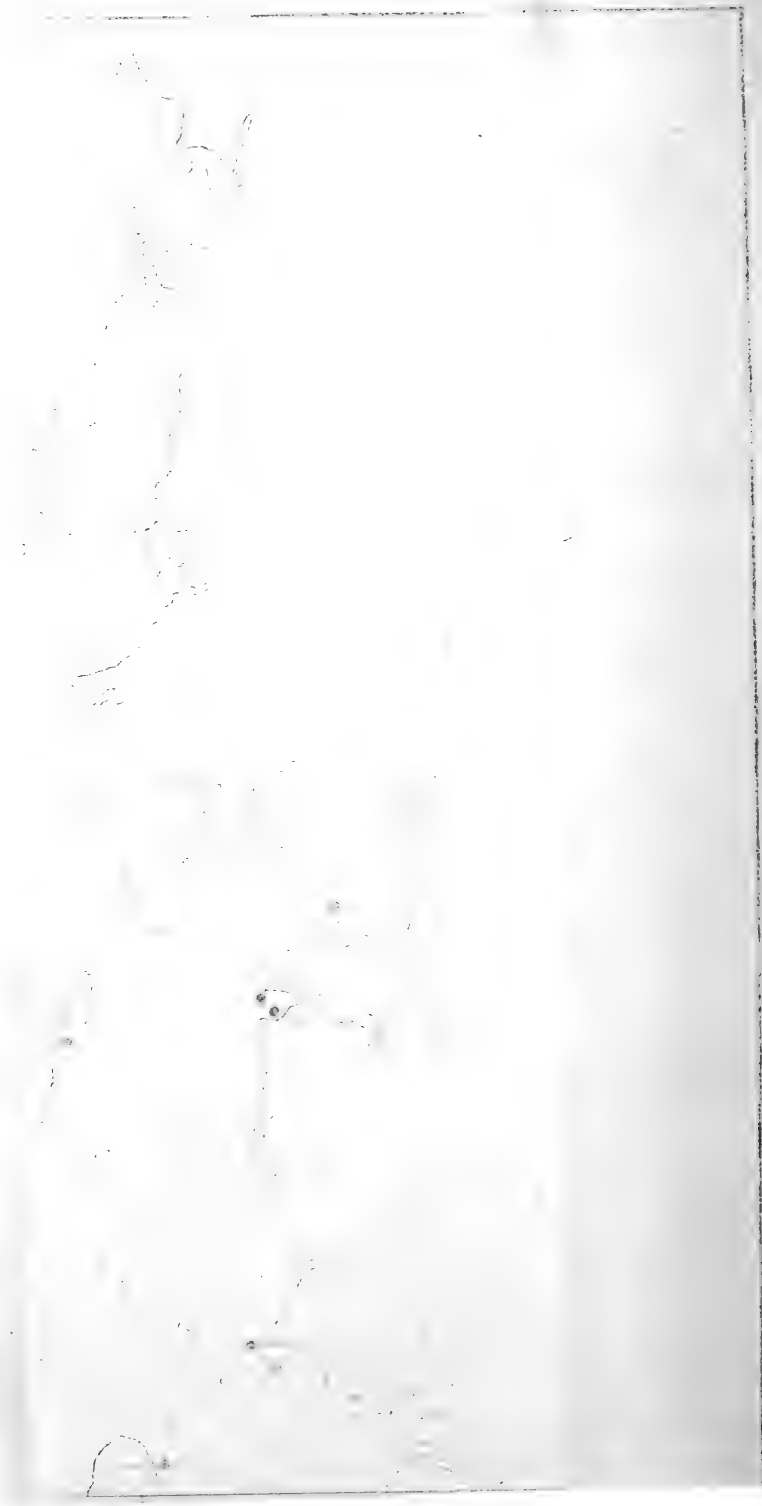
Almy, Frank K.	Sakonnet River.
Brownell, Gilbert	" "
Cattle, Wm.	Tiverton.
Cattle, Wm.	"
Church, J. B.	Sakonnet Point.
Church, Daniel	" "
Church, Daniel	" "
Cory & Martin	" River.
Cory & Martin	" "
Cory, Edw. J.	" "
Cory, Edw. J.	" "
Cottrell, Samuel	Popasquash.
Cottrell, Samuel	Popasquash.
Cottrell, Samuel	Mt. Hope.
Cottrell, Samuel	Bristol.

Doan, S. P. . . . . Rumstick.
Durfee, Thomas . . . . Tiverton.
Durfee, Thomas . . . . "
Durfee, Thomas . . . . Hog Island.
Fish, Clinton . . . . Tiverton.
Gray, Geo. E. . . . . Sakonnet River.
Gray, Geo. E. . . . . Cory's Wharf, Sakonnet River.
Grinnell, Philip . . . . Sakonnet River.
Grinnell, Philip . . . . " "
Harvey, Wm. . . . . " "
Helger, Henry . . . . Prudence.
Helger, Henry . . . . "
Hoar, Fred H. . . . . Bristol.
Negus, Jos . . . . Tiverton.
Rice, Herbert . . . . Potowomut.
Rice, Herbert . . . . "
Riley, Tom . . . . Tiverton.
Seabury, Ben . . . . Sakonnet River.
Shepard, John . . . . Bristol.
Shepard, John . . . . Popasquash.
Simons, John M. . . . . Tiverton.
Simons, Wm. . . . . Sakonnet River.
Spink, J. W. . . . . Prudence.
Taber, Alonzo . . . . Tiverton.
Wilcox, Henry . . . . Sakonnet River.
Wilcox, J. S. . . . . Tiverton.
Wilcox Bros. (Ralph and Holder) . . . . Sakonnet River.
Wilcox Bros. " " . . . . " "
Wilcox Bros. " " . . . . " "
Wilson, A. A. . . . . Prudence.
Wilson & Mitchell . . . . Potowomut.

Calvert, Geo . . . . Coggeshall's Ledge.
Carpenter Bros . . . . South Ferry, Watson's Pier.
Carpenter, Geo . . . . Beaver Head.

Easterbrooks, Comer	Price's Neck.
Gladding, A. B.	Castle Hill.
Gladding, A. B	Coddington Cove.
Gladding, A. B.	Coddington Cove.
Goddard, Al.	Brenton's Point.
Harvey, Charles	West Shore.
Hicks, O. G.	Brenton's Point.
Lake, Isaac	Conanicut.
Lawton, Ned	Brenton's Cove.
Lawton, Ned	Mackerel Cove.
Lawton, W. H	Mackerel Cove.
Lewis, J. O. & G. A	Quonset Point.
Lewis, J. O. & G. A	Quonset Point.
Lewis, J. O. & G. A	Wild Goose Point.
Lewis Bros., W. A., F. A., T. W	Plum Beach.
Lewis Bros	Casey's Point.
Lewis, J. O. & G. A	Conanicut.
Lewis Bros	Conanicut.
Lewis Bros	Conanicut.
Manchester, Daniel	Quonset Point.
Manchester, Daniel	Quonset Point.
Mitchell, Gordon	Conanicut.
Northrup Bros	Beaver Tail.
Peckham Bros	Sachuest Point.
Rose, W. R	Coggeshall's Ledge.
Rose, W. R.	Conrad's Cove.
Spink, J. W	Conanicut.
Spink, J. W	Conanicut.
Spink, J. W	Beaver Head.
Tourjee, Stephen	Beaver Tail.
Tourjee, Stephen	Beaver Head.
Tourjee, Stephen	Sanderstown.
Two, Jean	Sachuest Point.
Wadsworth, Leman	Roane's Point.


NARRAGANSETT BAY
SHOWING THE LOCATION OF FISH TRAPS FOR 1898
AND POINTS AT WHICH DREDGINGS HAVE BEEN MADE.
STATUTE MILES
NAUTICAL MILES
PREPARED BY THE RHODE ISLAND COMMISSION OF INLAND FISHERIES
TO ACCOMPANY REPORT FOR 1898
RHODE ISLAND
Conanicut
Prudence
S.P. Doane
J. Shepard
S. Cottrell
Tuber
Cottrell
Simmons
Riley
Tiegus
Durfee
Brownell
Gray
Grinnell
Wilcox
Seabury
Grinnell
Almy
Simmons
Wilcox Bros
Corey
Gladding
Harvey
Nilson
Lawton
Rose
Lewis Bros
Tourjee
Carpenter Bros
Spink
Mitchell
Church
Brightman
Rose



Sea Traps.

Brightman, W. J	Coggeshall's Ledge.
Brightman, W. J	Seal Rock.
Brightman, W. J	Off Cormorant Rock.
Brownell, J. M	Seal Rock.
Church, J. B	Coggeshall's Ledge.
Cottrell, Geo. F	Off Cormorant Rock.
Church, J. B	Off Cormorant Rock.
Cottrell, Geo. F	Off Seal Rock.
Gladding, A. B	Coggeshall's Ledge.
Lewis, Frank	Seal Rock.
Macomber, Frank	Off Cormorant Rock.
Rose, G. O	Coggeshall's Ledge.
Rose, W. R	Seal Rock.
Rose, W. H	Off Cormorant Rock.
Thompson, Noah	Off Seal Rock.

In the above list the sea traps are located as off Seal Rock, Coggeshall's Ledge, Cormorant Rock. They are arranged in three long series, extending as will be seen by reference to the chart accompanying this report.

V. *The Physical and Biological Examination of the Waters of the Bay.*

A physical examination of the shore waters of the State has been made for the purpose of establishing a standard, variations from which, from time to time, will be recorded. The Commission regrets that such physical examination as it thus far has been enabled to make covers only a portion of the year, for the measurements of the salinity of water, to be of permanent value, should include the entire twelve months. When observations of density are taken for only a limited time it is quite possible that, as a result of prevailing wind or excessive rain-fall, the data secured is extreme, and consequently not representative of the average con-

ditions. The limited resources of the Commission, however, have prevented them from giving the attention to this subject which it really deserves.

Four hundred and eighty-four specific gravity and temperature observations have been taken.

In perfectly pure fresh water the salinometer reading is 1.000; but as the water becomes hard, through the addition of salts, the readings of the salinometer increase, and in the open ocean, near Block Island, the heaviest water taken had a specific weight of 1.025; and at no locality south of the line drawn from Beaver Tail to Sakonnet was it of less density than 1.023. As we ascend the Bay the water becomes less and less salt, and readings as low as 1.020 were taken near Allen's Harbor, to the westward of Prudence Island, and near Bristol Ferry. The salinity of the water in the Providence river was considerably less, being 1.017 near Sassafras Point; although the surface water was only 1.008. As has already been stated, the record of a single series of specific gravity observations, in itself, is of no moment; but inasmuch as it is the purpose of the Commission to add extensively to the data during the coming year, this permanent record will prove of considerable value inasmuch as the salinity of the water bears upon the question of successful oyster culture.

Although, as is well known, fresh water is fatal to the oyster, and prolonged immersion in the water, even as fresh as 1.007, will very materially affect the marketable qualities of the animal, successful oyster culture cannot be carried on in water that is, for any considerable period, lighter than 1.011 or heavier than 1.022. Between these limits there are still large tracts of available ground in the upper portion of the bay which are still unoccupied by oyster culturists, and there are also a great many localities farther down the bay, near the openings of fresh water streams, where, with proper protection and freedom from the invasion of the starfish, oysters of fine quality may be raised.

The following section on biological conditions prevailing in the waters of the Bay and on the bottom, although technical, is of im-

portance, since the life in the water is the expression of the water's purity, average salinity, and average temperature. If the water in any portion of the bay becomes contaminated the life upon the bottom is immediately affected, and this is shown either by the migration of animals from the infected locality, or, in a case of animals unable to move about rapidly, by their death. Many of the animals found on or immediately below the surface of the mud bear shells which exist for many years after their soft parts have perished. It is possible, then, for one acquainted with the facies of the shore fauna, to state what the probable biological conditions have been. The animals which are found in colder water off shore are strikingly different from those found in the warm waters of the bay, as is beautifully illustrated by the distribution of the several species of starfish. Your Commission, therefore, has felt justified in recording, at considerable length, the physical and faunistic conditions in the different portions of the bay, and feels confident, in so doing, that they will materially assist in the work of future years.

Even in such a filthy portion of the Providence River as lies north of Field's Point, there is still a remarkably rich assemblage of life. This is in direct contradiction of what might have been predicted, and is sufficient ground for the belief that, with the expenditure of a little care in the disposal of sewerage and manufacturers' waste, important food fish might actually be caught from our wharves in sufficient numbers to be of economic importance. In this tract of the river two species of shrimp (*Crangon Palæmonetes*) abound; *Squilla*, or mantis shrimp, are repeatedly taken. *Platyonichus*, *Panopeus*, *Callinectes*, and *Libinia* represent the more common species of crabs, while a small hermit (*Eupagurus*) is taken at nearly every cast of the dredge. The following molluscs and vertebrates were taken: *Ilyanassa*, *Venus*, *Mulinea*, *Sycotypus*, *Mytilus*, *Tritia*, *Mya*, skate (*Ria*), flat-fish (*Pseudopleuronectes*), and a pipe-fish (*Siphostoma*). Starfish of small size also grow in this locality. Farther down the river, between Rocky Point and Rumstick, the water becomes relatively clean, and sev-

eral additional forms are found. Stars have become large and very abundant. All of the crustacea and molluscs above mentioned are found in increased numbers, and to these may be added *Pelia*, *Cancer*, *Yoldia*, *Clidiophora*, and *Eupleura*. The further distribution of animals can be more readily understood by confining our attention to the stations at which observations were made by the "Fish Hawk."

Record of Dredging *by U.S. Fish Commission Steamer "Fish Hawk," Lt.-Com'd'r Richard G. Davenport, U.S. Navy, commanding.*

(In service of U. S. Fish Commission).

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature.		Density.		Contents.
						Surface.	Bottom.	Surface	Bottom.	
1	Oct. 26.	33 ft.	Sand, shell	Dredge	62° F.	15.0° C.	61.0° F. 14.5° C	1.022	1.022	Nothing in dredge.
2	Oct. 28.	22½ ft.	Black mud	7 ft. trawl	51° F.	12.5° C.	13.0° C.	1.017	1.019	Squilla, Crangon, Palæmonetes, Ilyanassa, Tritia (dead), Mya (dead).
3	Oct. 28.	22½ ft.	Black mud	7 ft. trawl	51° F.	13.0° C.	13.5° C.	1.011	1.017	Platyonichus, Crangon, Eupagurus, Venus, Mulinea, Ilyanassa.
4	Oct. 28.	27 ft.	Black mud	7 ft. trawl	52° F.	13.0° C.	14.0° C.	1.007	1.017	Common Star, Crangon, Panopeus, Balanus, Mulinea, Ilyanassa, Sycotypus, Mytilus, Hydroids, Raja, Pseudopleuronectes, Syphostoma.
5	Oct. 28.	28½ ft.	Black mud	7 ft. trawl	53° F.	13.0° C.	13.0° C.	1.008	1.018	Squilla, Crangon, Balanus, Eupagurus, Mulinea, Ilyanassa, Pseudopleuronectes, Rhynchobolus.
6	Oct. 28.	22½ ft.	Black mud	7 ft. trawl	54° F.	13.5° C.	14.0° C.	1.007	1.017	Common Star, Callinectes, Libinia, Mulinea, Tritia, Mya.
7	Oct. 28.	31½ ft.	Black mud	7 ft. trawl	56° F.	14.0° C.	14.0° C.	1.008	1.018	Platyonichus, Crangon, Mulinea, Crepidula, Hydroids.
8	Oct. 28.	4—6 fath.	Mud	7 ft. trawl	57° F.	13.5° C.	13.0° C.	1.020	1.020	Large Common Stars, Squilla, Callinectes, Pelia, Eupagurus, Panopeus, Palæmonetes, Yoldia, Clidiophora, Tritia, Ilyanassa, Mulinea, Raja, Bothus.
9	Oct. 28.	3½–4½ fath.	Mud	7 ft. trawl	50° F	13.5° C.	13.0° C.	1.019	1.020	Common Star, Cancer, Crangon, Eupleura, Mulinea, Tritia, Yoldia, Clidiophora, Cistenides.
10	Oct. 31.	15 fath.	Mud and sand	7 ft. trawl	57° F.	12.6° C.	13.0° C.	1.022	1.024	Nothing in trawl.
11	Oct. 31.	12 fath.	Sand	10 ft. trawl	53° F.	12.7° C.	13.4° C.	1.022	1.024	Maroon Stars, Eupagurus, Crangon, Tritia, Raja, Hake.

RECORD OF DREDGING.—*Continued.*

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature.		Density.		Contents.
						Surface	Bottom.	Surface.	Bottom.	
12	Oct. 31.	12 fath.....	Sand..................	10 ft. trawl	53° F.	13.0° C.	13.6° C.	1.022	1.023	Common Stars, Purple Stars, Cancer, Callinectes, Gammarus, Limulus, Tritia, Hydroids, Astyris, Nudibranch, several fish.
13	Oct. 31.	11 fath.....	Sticky.................	10 ft. trawl	56° F.	13.0° C.	13.0° C.	1.022	1.024	Purple Stars, Maroon Stars, Cancer, Caprella, Gammarus, Eupagurus, Nucula, Tritia, several fish.
14	Oct. 31.	19½ fath....	Sticky...........	10 ft. trawl	55° F.	13.1° C.	13.3° C.	1.022	1.0235	Maroon Stars, Pandalus, several fish.
15	Oct. 31.	13½ fath....	Hard sand............	10 ft. trawl	54° F.	13.0° C.	13.5° C.	1.022	1.0235	Cribrella, Cancer, Pandalus, Pecten, Modiola, several fish.
16	Oct. 31.	15 fath.....	Hard..................	10 ft. trawl	54° F.	13.0° C.	13.1° C.	1.022	1.024	Purple Stars, Eupagurus, Pinnotheres, Pandalus, Pecten (tenu-icostatus), Buccinum, Hydroids, several fish.
17	Nov. 1.	9½ fath.....	Rocks and sand........	10 ft. trawl	56° F.	12.8° C.	13.0° C.	1.023	1.024	Purple Stars, Hydroids, Urosalpinx, Astyris, Anomia, Saxicava, Lepidonotus, Cliona.
18	Nov. 1.	13 fath.....	Rocks and sand........	7 ft. bm. trawl.	53° F.	12.9° C.	13.1° C.	1.023	1.024	Maroon Stars, Cribrella, Eupagurus, Crangon, Tritia, Crepidula, Cliona.
19	Nov. 1.	13 fath.....	Rocks and sand........	7 ft. bm. trawl.	52° F.	13.0° C.	13.5° C.	1.023	1.024	Small Purple Stars, Cribrella, Eupagurus, Urosalpinx, Tritia, Corbula, Mytilus, Anachis, Cliona, Astrangia, Ophiopholis, Amarœcium.
20	Nov. 1.	22½ fath....	Sticky, rough..........	Small dredge..	52° F.	13.7° C.	13.8° C.	1.023	1.024	No Starfish. Unciola, Small Amphipods, Neptunea, Yoldia, Tritia, Small Holothurians, Clidiophora (alive), Cyprina, Astarte, Cardium (dead), Sternaspis. Specimens from this station not all identified.
21	Nov. 1.	22 fath.....	Sandy..................	7 ft. bm. trawl.	55° F.	13.0° C.	13.0° C.	1.023	1.024	Purple Stars, Maroon Stars, Cribrella, Crangon, Pandalus, Eupagurus, Cancer, Caprella, Unciola, Isopods, Tritia, Neptunea, Pecten, Lucina (dead), Ilyanassa, Suberites, several fish.

Record of Dredging.—*Continued.*

Station.	Date. 1898.	Depth.	Bottom.	Instrument	Air.	Temperature.		Density.		Contents.
						Surface.	Bottom	Surface.	Bottom.	
22	Nov. 1.	22 fath.....	Hard sandy...........	7 ft. bm. trawl.	54° F.	13.1° C.	13.2° C.	1.023	1.023	Purple Stars, Maroon Stars, Pandalus, Eupagurus, Crangon, Cancer, Pecten, Crepidula, Buccinum, Cyprina (dead), Neptunea (dead), Hydroids, several fish, Squid.
23	Nov. 1.	20 fath.....	Hard sand............	7 ft. bm. trawl.	53° F.	13.1° C.	12.7° C.	1.023	1.0235	Maroon Stars, Purple Stars, Cribrella, Green Urchins, Holothurians, Eupagurus, Pandalus, Cancer, Crangon, Pecten, Crucibulum, Squid, Hydroids, Alcyonium, several fish.
24	Nov. 1.	16 fath.....	Hard sand............	7 ft. bm. trawl.	51° F.	13.0° C.	12.9° C.	1.023	1.023	Maroon Stars, Purple Stars, Cribrella, Echinarachnius, Holothurians, Pandalus, Eupagurus, Cancer, Squid, Mactra, Astarte, Pecten, Cyclocardia, Anachis, Hydroids, several fish.
25	Nov. 1.	13 fath.....	Hard gravelly.........	7 ft. bm. trawl.	50° F.	13.0° C.	12.7° C.	1.023	1.025	Purple Stars, Holothurians, Echinarachnius, Pandalus, Caprella, Crangon, Eupagurus, Cancer, Mactra, Astarte, Tritia, Lunatia, Sponge, Hydroids, Bugula, several fish.
26	Nov. 2.	7½ fath.....	Mussel bed	7 ft. bm. trawl.	56° F.	12.7° C.	13.0° C.	1.022	1.026	Common Stars, Cribrella, Brittle Star, Arbacia, Panopeus, Pinnotheres, Eupagurus, Mytilus, Crepidula, Urosalpinx, Pennaria, Hydractinia, Trophonia, Lepidonotus, Bugula, several fish, shells.
27	Nov. 2.	10¼ fath....	Stony, shelly.........	7 ft. bm. trawl.	56° F.	12.5° C.	13.0° C.	1.022	1.022	Common Stars, Heteromysis, Panopeus, Crangon, Eupagurus, Crepidula, Urosalpinx, Tritia, Serpula, Lepidonotus, Bryozoa, Hydroids, Microciona, shells.
28	Nov. 2.	9 fath......	Hard sandy...........	7 ft. bm. trawl.	56° F.	12.3° C.	13.0° C.	1.021	1.022	Common Stars, Cribrella, Panopeus, Amphipods, Lepidonotus, Cliona, Escharella, shells.

RECORD OF DREDGING.—*Continued.*

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature. Surface.	Temperature. Bottom.	Density. Surface.	Density. Bottom.	Contents.
29	Nov. 2.	7 fath......	Sandy......	7 ft. bm. trawl.	57° F.	12.3° C.	12.7° C.	1.021	1.023	Common Star, Crangon, Amphipods, Panopeus, Eupagurus, Crepidula, Tritia, Serpula, Lepidonotus, Cliona, Hydroids, few fish.
30	Nov. 2.	5 fath......	Sticky mud...........	7 ft. bm. trawl.	57° F.	12.2° C.	13.0° C.	1.021	1.022	Common Star, Crangon, Pelia, Eupagurus, Teredo, Nucula, Mulinea, Clidiophora, Eupleura, Argina, Lyonsia, Serpula, Cistenides, Botryllus, Metridium, several fish, shells.
31	Nov. 2.	5 fath......	Muddy................	7 ft. bm. trawl.	56° F.	12.1° C	12.7° C.	1.020	1.025	Common Star, Eupagurus, Pelia, Cancer, Crangon, Yoldia, Clidiophora, Crepidula, Nucula, several fish, shells.
32	Nov. 2.	5 fath......	Muddy, shelly.........	7 ft. bm. trawl.	56° F.	12.2° C.	12.6° C.	1.021	1.024	Common Star, Squilla, Panopeus, Pinnixa, Crangon, Pelia, Yoldia, Clidiophora, Eupleura, Mulinea, Annelids, Cliona, several fish, shells.
33	Nov. 2.	4½ fath.....	Muddy................	7 ft. bm. trawl.	56° F.	12.0° C.	12.5° C.	1.021	1.025	Common Stars, Cancer, Squilla, Crangon. Sycotypus, Clidiophora, Yoldia, Anomia, Tritia, several fish, shells.
34	Nov. 2.	4½ fath.....	Muddy................	7 ft. bm. trawl.	56° F.	12.1° C.	12.6° C.	1.021	1.022	Common Stars, Squilla, Crangon, Panopeus, Crepidula, Eupleura, Callista, Mulinea, Yoldia, Serpula, Cliona, several fish, shells.
35	Nov. 2.	8 fath......	Muddy................	7 ft. bm. trawl.	56° F.	13.0° C.	13.2° C.	1.021	1.023	Common Stars, Crangon, Eupagurus, Cancer, Yoldia, Pecten, Astarte, Annelids, Hydractinia, Tubularia, several fish, shells.
36	Nov. 2.	7 fath......	Muddy................	7 ft. bm. trawl.	56° F.	12.7° C.	13.0° C.	1.021	1.023	Common Stars, Green Urchin, Eupagurus, Astarte, Clidiophora, Cyclocardia, Pecten, Thracia, Littorina, Tritia, Yoldia, Trophonia, several fish, shells.

Record of Dredging.—*Continued.*

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature. Surface.	Temperature. Bottom.	Density. Surface.	Density. Bottom.	Contents.
37	Nov. 3.	18 fath.....	Hard, rock and sand..	7 ft. bm. trawl.	52° F.	13.4° C.	13.6° C.	1.023	1.023	Common Stars, Purple Stars, Cribrella, Eupagurus, Tritia, Bugula, Bryozoa, Alcyonium, Cliona, Amarœcium, several fish.
38	Nov. 3.	19 fath.....	Hard sandy...........	7 ft. bm. trawl	52° F.	13.6° C.	14.1° C.	1.023	1.023	Common Stars, Purple Stars, Maroon Stars, Brittle Stars, Pandalus, Eupagurus, Cancer, Squid, Tritia, Lunatia, Cyprina (dead), Lepidonotus, Pennaria, several fish.
39	Nov. 3.	20 fath.....	Hard sandy...........	7 ft. bm. trawl.	53° F.	13.5° C.	13.5° C.	1.023	1.023	Common Stars, Maroon Stars, Purple Stars, Holothurians, Green Urchins, Eupagurus, Pandalus, Isopods, Cancer, Squid, Crepidula, Cyclocardia, Lucina (dead), Tritia, Spirorbis, Bryozoa, several fish.
40	Nov. 3.	18 fath.....	Sand..................	7 ft. bm. trawl.	53° F.	12.8° C.	13.2° C.	1.023	1.024	Purple Stars, Maroon Stars, Brittle Stars, Arbacia, Cancer, Caprella, Pandalus, Eupagurus, Isopod, Pycnogonid, Squid, Pecten, Modiola, Buccinum, Crucibulum (dead), Chiton, Hydroids, shells, several fish.
41	Nov. 3.	7¼ fath.....	Gravelly..........	7 ft. bm. trawl.	54° F.	13.2° C.	13.0° C.	1.023	1.023	Purple Stars, Brittle Star, Cribrella, Isopods, Amphipods, Crangon, Cancer, Squid, Nudibranch, Anachis, Astyris, Tritia, Pennaria, Astrangia, Spirorbis, Sponge.
42	Nov. 3.	20¼ fath....	Sand, gravelly.........	7 ft. bm. trawl.	57° F.	13.3° C.	13.2° C.	1.023	1.023	Maroon Stars, Purple Stars, Pandalus, Eupagurus, Pecten, Crucibulum, Cyclocardia, Neptunea, Squid, Crepidula, Tubularia, Alcyonium, Anemone, several fish.
43	Nov. 3.	20 fath.....	Sandy, gravelly........	7 ft. bm. trawl.	57° F.	13.1° C.	13.2° C.	1.023	1.023+	Maroon Stars, Echinarachnius, Pandalus, Eupagurus, Cancer, Crangon, Pecten, Tritia, Astarte, Neptunea, Coral, Alcyonium, several fish.

RECORD OF DREDGING.—*Continued.*

STATION.	DATE, 1898.	DEPTH.	BOTTOM.	INSTRUMENT.	AIR.	TEMPERATURE.		DENSITY.		CONTENTS.
						SURFACE.	BOTTOM.	SURFACE.	BOTTOM.	
44	Nov. 3.	16 fath.....	Hard sand............	7 ft. bm. trawl.	56° F.	13.3° C.	13.7° C.	1.023	1.023+	Maroon Stars, Echinarachnius, Pandalus, Eupagurus, Crucibulum, Squid, Pecten, Tritia, Lunatia, Crepidula, several fish.
45	Nov. 3.	17½ fath....	Sandy.................	7 ft. bm. trawl.	56° F.	13.0° C.	13.2° C.	1.023+	1.021	Maroon Stars, Echinarachnius, Pandalus, Eupagurus, Squid, Lunatia, Tritia, Buccinum, Suberites, several fish.
46	Nov. 4.	18 fath.....	Sandy, shelly.........	7 ft. bm. trawl.	58° F.	13.3° C.	14.0° C.	1.023	1.023+	Maroon Stars, Echinarachnius, Pandalus, Eupagurus, Crangon, Crucibulum, Crepidula, Buccinum, Squid, Tritia, Neptunea, Cyprina (dead), Hydractinia, Tubularia, Suberites, several fish.
47	Nov. 4.	14 fath.....	Sandy.................	7 ft. bm. trawl.	59° F.	13.3° C.	13.3° C.	1.023	1.024	Maroon Stars, Echinarachnius, Pandalus, Cancer, Crangon, Crepidula, Tritia, Buccinum, Spirorbis, several fish.
48	Nov. 4.	9½ fath.....	Sand, gravel..........	7 ft. bm. trawl.	57° F.	13.0° C.	12.5° C.	1.023	1.023	Common Stars, Maroon Stars, Echinarachnius, Eupagurus, Libinia, Crangon, Pelia, Buccinum, Urosalpinx, Lunatia, Tritia, Chalina, several fish.
49	Nov. 4.	5 fath......	Gravelly..............	7 ft. bm. trawl.	60° F.	12.0° C.	12.1° C.	1.022+	1.023	Maroon Stars, Crangon, Eupagurus, Balanus, Crepidula, Littorina, Tritia, Hydractinia, Ciona, Chalina, several fish.
50	Nov. 4.	4¾ fath.....	Rocky.................	7 ft. bm. trawl.	60° F.	12.0° C.	12.4° C.	1.022	1.023	Common Star, Balanus, Eupagurus, Pelia, Libinia, Crepidula, Urosalpinx, Neverita, Argina. Scapharca, Lunatia, Serpula, Lepidonotus, Eupleura (dead), Membranipora, Escharella, Hydractinia, several fish.
51	Nov. 4.	5¼ fath.....	Rocky, gravelly.......	7 ft. bm. trawl.	61° F.	11.8° C.	12.2° C.	1.022	1.022	No Stars. Pelia, Callinectes, Cancer, Libinia, Eupagurus, Panopeus, Anomia, Cerithiopsis, Scapharca, Balanus, Lepidonotus, Bryozoa, Hydroids, Hydractinia, Microciona, several fish, shells.

RECORD OF DREDGING.—*Continued.*

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature.		Density.		Contents.
						Surface.	Bottom.	Surface.	Bottom.	
52	Nov. 4.	4 fath......	Rocky, gravelly........	7 ft. bm. trawl.	61° F.	11.5° C.	12.0° C.	1.022	1.022	Common Stars, Argina, Crangon, Cancer, Balanus, Pelia, Eupagurus, Libinia, Anomia, Mulinia, Crepidula, Hydroids, Hydractinia, Microciona, several fish, shells.
53	Nov. 4.	7 fath......	Mussel bed............	7 ft. bm. trawl.	56° F.	13..° C.	13.8° C.	1.021+	1.022+	Common Stars, Arbacia, Cancer, Panopeus, Pinnotheres, Callinectes, Mytilus, Lepidonotus, several fish, shells.
54	Nov. 4.	$7\frac{1}{4}$ fath.....	Rocky..................	7 ft. bm. trawl.	56° F.	12.8° C.	13.7° C.	1.021+	1.022	Common Stars, Purple Stars, Strongylocentrotus, Cancer, Idotea, Eupagurus, Gammarus, Panopeus, Squid, Mytilus, Crepidula, Buccinum, Spirorbis, Lepidonotus, Bryozoa, Laminaria, several fish, shells.
55	Nov. 4.	$9\frac{1}{2}$ fath.....	Sandy..................	7 ft. bm. trawl.	56° F.	13.6° C.	14.0° C.	1.022	1.023	No Stars. Pelia, Cancer, Eupagurus, Crangon, Gammarus, Mytilus, Sycotypus, Lunatia, Tritia, Nudibranch, Mactra, Laminaria, shells bored by drill, several fish.
56	Nov. 4.	$14\frac{3}{4}$ fath....	Rocky, sandy..........	7 ft. bm. trawl.	53° F.	13.0° C.	13.3° C.	1.022	1.022	Common Stars, Maroon Stars, Purple Stars, Pandalus, Cancer, Callista, Cyclocardia, Lunatia, Anomia, Cyprina (dead), Tritia, several fish.
57	Nov. 4.	$17\frac{1}{2}$ fath....	Rocky, sandy..........	7 ft. bm. trawl.	51° F.	12.5° C.	13.0° C.	1.021+	1.023	Common Stars, Purple Stars, Maroon Stars, Pandalus, Libinia, Eupagurus, Astarte, several fish, shells.
58	Nov. 9.	$4\frac{1}{4}$ fath.....	Muddy	7 ft. bm. trawl.	58° F.	11.3° C.	12.7° C.	1.019	1.022+	Twenty-four Common Stars, $2\frac{1}{2}$–6 inches across.
59	Nov. 9.	$4\frac{3}{4}$ fath.....	Muddy, with gravel...	7 ft. bm. trawl.	60° F.	11.5° C.	12.5° C.	1.019	1.021	One hundred Common Stars, $2\frac{1}{2}$–6 inches across.
60	Nov. 9.	$6\frac{1}{4}$ fath.....	Mussel bed............	7 ft. bm. trawl.	62° F.	12.0° C.	13.0° C.	1.019	1.020+	Over one hundred Common Stars, nearly all large size, 6—8 inches across; a few 3—4 inches across.

RECORD OF DREDGING.—*Continued.*

STATION.	DATE, 1898.	DEPTH.	BOTTOM.	INSTRUMENT.	AIR.	TEMPERATURE. SURFACE.	TEMPERATURE. BOTTOM.	DENSITY. SURFACE.	DENSITY. BOTTOM.	CONTENTS.
61	Nov. 9.	15 fath.....	Hard	7 ft. bm. trawl.	62° F.	11.9° C.	13.6° C.	1.021	1.021	Five Common Stars, 1—3½ inches across; one Brittle Star, one Red Star (*Cribrella*).
62	Nov. 9.	15 fath.....	Shelly	7 ft. bm. trawl.	60° F.	12.0° C.	14.1° C.	1.020	1.021+	Nearly eighteen hundred Common Stars, 4—6 inches across, some larger; one dozen Red Stars (*Cribrella*), different sizes.
63	Nov. 12	8½ fath.....	Rocky.	Dredge	38° F.	11.4° C.	10.8° C.	1.023+	1.023	(Rocky bottom; dredge torn off and lost).
64	Nov. 12	11 fath. ...	Rocky and sandy......	Dredge	38° F.	12.8° C.	12.0° C.	1.023	1.023	No Stars.
65	Nov. 12	9½ fath.....	Rocky and sandy......	Dredge	38° F.	11.3° C.	12.0° C.	1.023	1.023+	No Common Stars. Eight Purple Stars, 1—1½ inches across; a number of small Red Stars (*Cribrella*).
66	Nov. 12	11½ fath....	Rocky.	Dredge	38° F.	11.9° C.	11.2° C.	1.023	1.023	No Stars.
67	Nov. 12	7 fath......	Rocky.	7 ft. bm. trawl.	39° F.	10.8° C.	11.0° C.	1.023	1.023+	No Stars.
68	Nov. 12	6 fath......	Rocky.	7 ft. bm. trawl.	40° F.	11.0° C.	11.3° C.	1.023	1.023+	No Common Stars. A few small Red Stars (*Cribrella*).
69	Nov. 12	5 fath......	Hard	Dredge	44° F.	10.8° C.	11.0° C.	1.023	1.023	No Stars.
70	Nov. 12	6½ fath.....	Hard	Dredge	44° F.	10.8° C.	11.0° C.	1.023	1.023	No Stars.
71	Nov. 12	8¼ fath.....	Sand and shell	Dredge	44° F.	11.7° C.	12.0° C.	1.023	1.023+	No Stars.
72	Nov. 12	7¼ fath.....	Fine gravel and shell..	Dredge	44° F.	11.8° C.	11.4° C.	1.023	1.023	No Common Stars. Two small Purple Stars; a few small Red Stars (*Cribrella*).
73	Nov. 12	5½ fath.....	Sandy and rocky......	7 ft. bm. trawl.	44° F.	11.5° C.	11.1° C.	1.023	1.023+	No Stars.
74	Nov. 12	8¼ fath.....	Hard	7 ft. bm. trawl.	45° F.	11.8° C.	11.7° C.	1.023	1.023	No Stars.
75	Nov. 12	3½ fath.....	Hard	7 ft. bm. trawl.	45° F.	11.8° C.	11.4° C.	1.023	1.023	No Stars.
76	Nov. 14	$\frac{7}{10}$ fath....	Rocky, and mussel bed	7 ft. bm. trawl.	52° F.	11.0° C.	11.2° C.	1.022	1.022+	Fifty-four Common Stars, 3—7 inches across, mostly large; one very small Star.

RECORD OF DREDGING.—*Continued.*

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature.		Density.		Contents.
						Surface.	Bottom.	Surface.	Bottom.	
77	Nov. 14	$9\frac{1}{2}$ fath.....	Mussel bed, muddy....	7 ft. bm. trawl.	52° F.	10.8° C.	11.0° C.	1.022	1.022+	About two hundred Common Stars, very numerous and large; one Red Star (*Cribrella*).
78	Nov. 14	$7\frac{1}{2}$ fath.....	Rocky...........	7 ft. bm. trawl.	52° F.	10.6° C.	10.8° C.	1.0216	1.022	Two dozen Common Stars, $1\frac{1}{2}$—4 inches across.
79	Nov. 14	6 fath......	Rocky and shelly......	7 ft. bm. trawl.	51° F.	10.4° C.	10.5° C.	1.022	1.022	One small Common Star, regenerating.
80	Nov. 14	5 fath......	Mussel bed, rocky.....	7 ft. bm. trawl.	52° F.	10.5° C.	10.7° C.	1.021	1.021+	Fourteen Common Stars, 1—3 inches across.
81	Nov. 14	4 fath......	Muddy................	7 ft. bm. trawl.	52° F.	10.2° C.	10.7° C.	1.021	1.021+	Nearly one hundred Common Stars, 1—5 inches across.
82	Nov. 14	$3\frac{3}{4}$ fath.....	Muddy................	7 ft. bm. trawl.	52° F.	10.0° C.	10.1° C.	1.020	1.021	One hundred and twenty small Common Stars, 1—3 inches across.
83	Nov. 14	$4\frac{3}{4}$ fath.....	Muddy, shelly.........	7 ft. bm. trawl.	52° F.	10.1° C.	10.0° C.	1.020+	1.022+	About one hundred and seventy-five Common Stars, $1\frac{1}{2}$—4 inches across.
84	Nov. 14	$4\frac{1}{2}$ fath.....	Muddy, shelly.........	7 ft. bm. trawl.	52° F.	10.0° C.	10.0° C.	1.020	1.021	About one hundred and fifty Common Stars, $1\frac{1}{2}$—4 inches across.
85	Nov. 14	$4\frac{1}{2}$ fath.....	Shelly, muddy.........	7 ft. bm. trawl.	52° F.	10.0° C.	9.8° C.	1.020	1.020+	Over eighty Common Stars, 1—4 inches across.
86	Nov. 14	$12\frac{1}{4}$ fath....	Hard	7 ft. bm. trawl.	48° F.	11.0° C.	10.8° C.	1.022	1.022	Two dozen Common Stars, 1—4 inches across.
87	Nov. 14	24 fath.....	Hard	7 ft. bm. trawl.	48° F.	11.0° C.	10.7° C.	1.021+	1.022+	Over two dozen Common Stars.
88	Nov. 14	19 fath.....	Hard	7 ft. bm. trawl.	46° F.	10.3° C.	10.6° C.	1.021	1.021+	No Common Stars. One Red Star (*Cribrella*); a few small Serpent Stars.
89	Nov. 15	8 fath......	Very rocky............	Dredge	40° F.	12.7° C.	11.3° C.	1.023+	1.024+	No Stars. (Dredge torn to pieces.)
90	Nov. 15	14 fath.....	Fine gravel and sand.	Dredge	40° F.	12.0° C.	11.3° C.	1.023+	1.024	No Stars.

RECORD OF DREDGING.—*Continued.*

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature.		Density.		Contents.
						Surface.	Bottom.	Surface.	Bottom.	
91	Nov. 15	12 fath.....	Hard gravelly.........	Dredge	40° F.	12.0° C.	11.4° C.	1.023+	1.023+	No Common Stars. Red Star (*Cribrella*) small and plentiful.
92	Nov. 15	15½ fath....	Hard..................	Dredge	41° F.	11.4° C.	11.2° C.	1.023+	1.023+	No Stars.
93	Nov. 15	6¼ fath.....	Sandy, hard...........	Dredge	42° F.	11.2° C.	11.5° C.	1.023	1.023	No Common Stars. One small Purple Star, ¼ inch across.
94	Nov. 15	7¾ fath.....	Hard, shelly..........	Dredge	42° F.	11.3° C.	11.5° C.	1.023	1.023	No Stars.
95	Nov. 15	10 fath.....	Hard, shelly..........	Dredge	44° F.	11.2° C.	11.8° C.	1.023	1.023+	No Common Stars. One small Maroon Star, 3 inches across.
96	Nov. 15	7¾ fath.....	Hard	7 ft. bm. trawl.	43° F.	11.2° C.	11.8° C.	1.023+	1.023+	No Stars.
97	Nov. 15	10 fath.....	Hard	7 ft. bm. trawl.	44° F.	11.3° C.	12.1° C.	1.022+	1.023+	No Stars.
98	Nov. 15	10 fath.....	Hard	7 ft. bm. trawl.	44° F.	11.6° C.	12.8° C.	1.023	1.023	No Stars.
99	Nov. 15	10½ fath....	Hard	7 ft. bm. trawl.	44° F.	11.6° C.	12.5° C.	1.023	1.023	One Common Star, 5 inches across.
100	Nov. 15	6½ fath.....	Hard	7 ft. bm. trawl.	45° F.	11.5° C.	12.0° C.	1.023	1.023	No Stars.
101	Nov. 15	6½ fath.....	Hard, rocky...........	7 ft. bm. trawl.	46° F.	11.5° C.	12.0° C.	1.023	1.023	No Common Stars. A number of small Red Stars (*Cribrella*).
102	Nov. 15	11 fath.....	Very rocky...........	7 ft. bm. trawl.	46° F.	12.0° C.	12.1° C.	1.023	1.023	No Common Stars. Several small Red Stars (*Cribrella*); a few Serpent Stars.
103	Nov. 15	9 fath......	Very rocky...........	7 ft. bm. trawl.	46° F.	11.5° C.	12.0° C.	1.023	1.023	No Common Stars. A few small Red Stars (*Cribrella*).
104	Nov. 15	6¾ fath.....	Very rocky...........	7 ft. bm. trawl.	48° F.	11.2° C.	11.8° C.	1.023	1.023	No Common Stars. A few small Red Stars (*Cribrella*).
105	Nov. 15	5 fath......	Stony......	Dredge	49° F.	11.0° C.	11.1° C.	1.023	1.023	Two small Common Stars, 1 inch across; three Purple Stars, 1—2½ inches across; a few Red Stars (*Cribrella*).

Record of Dredging.—*Continued.*

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature.		Density.		Contents.
						Surface.	Bottom.	Surface.	Bottom.	
106	Nov. 15	6¾ fath.	Gravelly, sandy	Dredge	47° F.	11.0° C.	10.3° C.	1.023	1.023	No Common Stars. Four small Purple Stars, 1—2½ inches across; a few Red Stars (*Cribrella*).
107	Nov. 15	7 fath.	Sandy, gravelly	Dredge	48° F.	11.0° C.	10.4° C.	1.023	1.023	No Stars.
108	Nov. 15	5¾ fath.	Gravel, sand	Dredge	47° F.	10.8° C.	10.1° C.	1.023	1.023	Eight Common Stars, ½—2½ inches across; a few Red Stars (*Cribrella*).
109	Nov. 15	5¾ fath.	Gravel, sand	10 ft. bm. trawl	47° F.	10.7° C.	10.8° C.	1.023	1.023	Five Common Stars, 1—2 inches across; two Purple Stars; a few Red Stars (*Cribrella*).
110	Nov. 15	5 fath.	Rocky	10 ft. bm. trawl	47° F.	11.0° C.	10.9° C.	1.023	1.023	One Common Star, one inch across; five Purple Stars, 1—2¼ inches across.
111	Nov. 16	10—20 fath.	Hard	7 ft. bm. trawl.	51° F.	12.2° C.	12.0° C.	1.022+	1.023	No Common Stars. Ten Maroon Stars, 2—4 inches across.
112	Nov. 16	26 fath.	Hard, smooth	7 ft. bm. trawl.	48° F.	11.2° C.	11.0° C.	1.022+	1.023	No Common Stars. Several small Purple Stars, 1½—4 inches across; a few Red Stars (*Cribrella*); one Serpent Star.
113	Nov. 16	23 fath.	Smooth, hard	7 ft. bm. trawl.	58° F.	11.0° C.	12.2° C.	1.022	1.023	No Common Stars. Two Purple Stars, 1½—2 inches across; a few Red Stars (*Cribrella*); one Serpent Star.
114	Nov. 16	9¾ fath.	Muddy, shelly	7 ft. bm. trawl.	54° F.	10.8° C.	11.0° C.	1.021+	1.023	Over one hundred Common Stars, medium size.
115	Nov. 16	15 fath.	Muddy, shelly	7 ft. bm. trawl.	58° F.	10.1° C.	10.5° C.	1.021	1.022—	Half-bushel Common Stars, 1—5 inches across.
116	Nov. 16	18 fath.	Clayey	7 ft. bm. trawl.	58° F.	10.1° C.	11.0° C.	1.020	1.022	Common Stars; one Serpent Star.
117	Nov. 16	13½ fath.	Soft, part hard	7 ft. bm. trawl.	50° F.	10.2° C.	11.0° C.	1.020	1.022+	One hundred and twenty-five Common Stars.
118	Nov. 16	15 fath.	Muddy, shelly	7 ft. bm. trawl.	50° F.	9.8° C.	11.3° C.	1.020	1.021+	About seventy-five small Common Stars.

RECORD OF DREDGING.—*Continued.*

Station.	Date, 1898.	Depth.	Bottom.	Instrument.	Air.	Temperature.		Density.		Contents.
						surface.	bottom.	surface	bottom.	
119	Nov. 16	11 fath.....	Muddy, shelly.........	7 ft. bm. trawl.	50° F.	9.8° C.	10.7° C.	1.020	1.023	About one hundred Common Stars, 1–6 inches across, mostly small.
120	Nov. 16	3¾ fath.....	Soft mud.............	7 ft. bm. trawl.	49° F.	9.8° C.	10.2° C.	1.020	1.021	Three Common Stars, 1¼—4 inches across.
121	Nov. 16	4 fath......	Muddy................	7 ft. bm. trawl.	49° F.	10.2° C.	11.0° C.	1.020	1.021	About fifty small Common Stars, 1½–4 inches across.

The following stations, 17—25, 37—43, 107—110, in Block Island Sound, could not be shown on the chart. They are located as follows:

17. Point Judith Light, N. ¼ E., 1¾ miles.
18. Point Judith Lighthouse, N.E. × E., 2.7 miles Mag.
19. Point Judith Lighthouse, N. × E. ½ E., 3¼ miles Mag.
20. Point Judith Light, N.E. ½ N., 4.7 miles Mag.
21. Block Island North Light, W. × S. ½ S., 3¾ miles Mag.
22. Block Island North Light, W. × N. ½ N., 4⅜ miles Mag.
23. Block Island South-east Light, S.W. ¾ W., 2¾ miles Mag.
24. Block Island South-east Lighthouse, N.W., 1.62 miles Mag.
25. Block Island South-east Lighthouse, N.E. ¼ E., 2.75 miles Mag.
37. Block Island North Light, S. ¼ E., 2.50 miles Mag.
38. Block Island North Light, E. × S., 1.75 miles Mag.
39. Block Island North Light, N.E. × E., 3.25 miles Mag.
40. Block Island North Light, N.E. ½ E., 4.50 miles Mag.
41. Block Island South-east Light, E. ¼ N., 3.50 miles Mag.
42. Block Island North-east Light, E. × N., 6 miles Mag.
43. Point Judith Light, N.W. ½ N., 7.25 miles Mag.
107. Point Judith Light, E. ½ S., 2.25 miles Mag.
108. Point Judith Light, W. × N. ¾ N., 3 miles Mag.
109. Point Judith Light, E. × S., 3.75 miles Mag.
110. Point Judith Light, E. ¾ S., 4.50 miles Mag.

VI. *The Investigation of the Plague which Destroyed Multitudes of Fish and Crustacea During the Fall of 1898.*

BY A. D. MEAD.

During the last two months the inhabitants of Rhode Island witnessed the following remarkable phenomenon. The water of a considerable portion of the bay became thick and red, emitting an odor almost intolerable to those living near by. The situation became alarming when, on the 9th and 10th of September, thousands of dead fish, crabs, and shrimps were found strewn along the shores or even piled up in windrows.

At the request of the Rhode Island Commission of Inland Fisheries, an investigation was made to determine the cause and extent of the unusual color of the water, and of the great mortality of the fish. The results of this investigation are briefly as follows:

During the last of August, throughout September and a part of October, streaks of red or "chocolate" water were observed from near Quonset Point and Prudence Island, north to Providence, and, on the flood tide, up the Seekonk river, nearly to Pawtucket, a range of about fifteen miles. In other parts of the bay, as far as could be learned, the phenomenon had not been observed.

On the 8th and 9th of September the water became extremely red and thick in various localities from East Greenwich to Providence, and the peculiar behavior of the marine animals attracted much attention. Myriads of shrimps and blue crabs, and vast numbers of eels, menhaden, tautog, and flat-fish came up to the surface and to the edge of the shore as though struggling to get out of the noxious water. Indeed, the shrimp and crabs were observed actually to climb out of the water upon stakes and buoys, and even upon the iron cylinders which support one of the bridges and which must have been very hot in the bright sun. In several instances, on these two days, hundreds of blue crabs were caught by a single individual in a few minutes' time, at the mouth of the Seekonk.

On the following day, September 10th, and for several days

afterwards, hardly a live crab or shrimp could be found. Along the shores, however, in the same vicinity, cartloads of dead shrimp were piled up in windrows, and among them were strewn great numbers of crabs and fish of various kinds, especially menhaden and eels. This singular behavior and alarming mortality of marine animals was reported from nearly every station at which the red water occurred, and from no other station, which indicates that the two phenomena are related as cause and effect.

It was commonly believed that dye-stuffs or other refuse emptied into the rivers at the upper part of the bay gave to the water its color and unpleasant odor, but microscopic examination showed that the water was swarming with minute organisms, species of *Peridinium*. The *Peridinium* is reddish brown in color and occurred in such excessive abundance that it gave to the water its peculiar color and odor, besides making it so opaque that one could hardly see a white shell six inches below the surface.

With regard to the systematic position of this organism there is a difference of opinion. It is, in fact, ranked with the animals by some authors, and with the plants by others. I have not yet been able to determine the species of our *Peridinium*. It resembles in many respects Carter's *Peridinium sanguineum*; it is much flattened, and the anterior end is distinctly bilobed, like *Peridinium tabulatum*, though the lobes are more rounded. Besides a flagellum extending forward from the ventral groove, a very large flagellum lies in the equatorial sulcus and entirely encircles the body. No cilia could be demonstrated.

After September 9th and 10th, when the great mortality of fish occurred, the *Peridinium* became, for a few days, less abundant, and then increased again until the 23d. There was a heavy rain on the 23d, and on the following day the water was comparatively clear. Since this date it has been more or less in evidence up to the day of writing (October 7th). On September 21st the number of *Peridinium* per cubic centimeter in the Seekonk river was estimated at 5,880. This was enough to give the water a very noticeable red color. Nevertheless, the marine animals appear not to

have been seriously affected since September 10th or 11th, though the approach of a streak of red water has, in some instances, interrupted good fishing.

In the Seekonk River the shrimp and crabs gradually returned, and in about three weeks after the sudden mortality were nearly as numerous as before, though the water was at times distinctly colored. On the 23d some shrimp, oysters, and small fish (*Fundulus*) were kept in the water where the *Peridinium* were the thickest, and suffered no apparent injury. In consideration of these facts, it has been doubted whether the *Peridinium* was the immediate cause of the peculiar behavior and death of the fish which occurred on the 9th and 10th of September, especially as the weather had been phenomenally hot for several weeks previous to those dates. I believe, however, that the *Peridinium* was the cause of the trouble, and not the hot weather or manufacturers' waste, for the following reasons:

On the two or three days in which the mortality took place the water was extremely red.

The hot weather was followed by a cold wave a day or two before the mortality commenced.

The phenomena occurred in Greenwich Bay and off Nayatt, many miles from any considerable source of contamination.

Finally, the phenomena in question were noticed by very many persons throughout the whole range of the red water, while in neighboring portions of the bay, for example, in the Warren River and in Bristol harbor, where the temperature of the water is quite as high as in the red-water districts, no *Peridinium* and no mortality or unusual behavior of the marine animals was reported, though the regions were carefully canvassed.

There are many recorded instances of salt and of fresh water colored red probably by *Peridinium* of this or a similar species. H. J. Carter, in his account of "The Red Coloring Matter of the Sea round the Shores of the Island of Bombay," described the new species *P. sanguineum*, which produces this effect. He points out, also, that Darwin's description of the animalcule which he found

to color the sea red, a degree south of Valparaiso, accords exactly with that of *Peridinium*. The animalcules which, according to Salt, produce the red color in the Red Sea, may be this form, and the same cause may perhaps be ascribed to the red color of the sea off Iceland in 1649. Carter quotes the following passage from an eye witness of a similar occurrence at Porebunder, on the coast of Khattywar, India, where the red water is extremely common: "The color of the sea water on Saturday evening last, the 27th of October, 1849, was changed from its usual tint to a deep red, emitting a most foul smell; the fish speedily were all destroyed and washed upon the beach in large quantities, etc." Though the narrator believed that this might be due to a submarine eruption of mud, Mr. Carter is inclined to ascribe it to some "animalcule," most probably *Peridinium*. He also directs attention to the Mosaic account of the plague of Egypt given in the following verses: "And all the waters that *were* in the river were turned to blood." "And the fish that *was* in the river died; and the river stank; and the Egyptians could not drink of the water of the river; and there was blood throughout all the land of Egypt."

VII. *The continuation of the observations begun in 1897 on the life habits of the starfish*—and

VIII. *A survey of the waters of the Bay and of the waters immediately off shore, for the purpose of determining the distribution of the starfish.*

Early in the investigation of the starfish problem it became evident that the starfish are not evenly distributed throughout the Bay, but that there were certain centres of distribution from which they migrated, often in great numbers, to adjoining mussel and oyster beds, and where during the breeding season they carried on the process of reproduction with great activity. The question naturally arose:—If the starfish in these areas of distribution and centres of reproduction could be exterminated, would they be eliminated permanently, or only temporarily owing to constantly recurring invasion from the outside waters through the

channels of the Sakonnet River and the East and West Passages? In other words, is the present excessive abundance of the starfish due to propagation within the waters of the Bay, or is it the result of migration from extra-territorial areas? If the former, efforts toward the annihilation of the pest would probably prove successful; if the latter, such efforts, except on a grand scale, would prove futile.

The Commission was materially aided in prospecting this line of work by the United States Commission of Fish and Fisheries, who generously detailed the steamer "Fish Hawk", amply equipped with scientific apparatus, and manned by an able body of men specially trained for this line of work.

The results of this investigation are most satisfactory, since they prove that the stars, so immediately damaging to the oyster, clam, and scallop industries, and, through the rapidity with which they devour the mussels, indirectly damaging to the general fisheries of the State, are actually the result of home breeding, and are probably never materially re-inforced through migration of the adults from outlying waters. Indeed, it is probable that even the larvæ are not brought into the Bay by the currents in such numbers as to materially affect the local biological conditions.

There are, besides the "red star" (Cribrella) and the "snake star" (Ophiopholis), three different varieties of starfish common to our coast. Of these, the first, or common star, is known to the fishermen as the "five-finger." The second is of more delicate texture, soft, and of a rich orange or maroon color. The third is of a purplish color. Of these varieties the first is the only one of economic interest at the present time, and the investigations have shown that, while it occurs in vast swarms within the waters of the Bay, it is only occasionally found in the heavier waters of the ocean. On the other hand, the "maroon stars" are frequently found off Brenton's Reef, along the shore line near Point Judith, and around Block Island. With the "maroon stars" are the still less abundant purple stars. The area of distribution of the common stars is thus seen to be practically limited by a line drawn

across the narrow portion of the mouth of the East and West Passages and the Sakonnet River. Above this line neither "purple" nor "maroon stars" occur, and below this line common "five-fingers" are very infrequent, and even when found are generally of small size. Whether the latter owe their distribution to the direct influence of the salinity of the water, temperature, nature of ocean bottom, depth, or food, we are unable to say, although it seems probable, from such observations as we have made, that the animals flourish in warmer and brackish water of moderate depth; this, however, may result from the fact that the stars find in this environment their most abundant food supply.

In certain localities, and particularly over mussel beds, the starfish are so numerous that they actually form a covering over the sea bottom. Mr. Gardiner has informed us that near the old Nayatt Light he has taken twelve hundred bushels of stars from four acres of sea bottom, an average of three hundred bushels to the acre. The average potato crop is 91.8 bushels per acre.* There is a long mussel bed lying in the west channel, and since, as Dr. Mead has shown, the reproductive energy of the star is directly dependent upon the food supply, there are places over this mussel bed where the starfish become gigantic in size, and where there are enough eggs extruded during the breeding period to keep the entire Bay stocked with the pest.

The Commission has located the enemy, tested its strength, is acquainted with its habits, and purposes to begin a war of extermination. Its first method will be to hire the necessary boats and go directly to the localities where the enemy is intrenched, dredge the stars from the bottom, and thus destroy the breeders. The Commission has consulted many of the leading oystermen, and is convinced that this method of procedure is practicable, and that the money expended will be many times returned in the increased receipts from the rental of land suitable for oyster culture.

The following is the special report of the investigations of Dr. A. D. Mead, made under the direction of the Commission.

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* In Rhode Island, 1880–1889.

SPECIAL REPORT ON THE STARFISH.

BY A. D. MEAD.

The investigation of the habits and life-history of the starfish has been continued during the past year, along the lines originally laid down by the Commission, and published in the last *Report*. The observations were made principally at the Kickemuit river, where the house-boat, moored over one of the oyster beds, served as a floating laboratory. Through the courtesy of the United States Fish Commission, in extending to me the privilege of the Woods Holl Station, and in giving me the use of one of the steam launches, I was able to make some observations upon the starfish of Buzzards Bay, and of other portions of Narragansett Bay. From the oystermen I have received valuable information and assistance, and on every occasion the kindest treatment.

The problems with regard to the starfish, which were originally suggested to me for solution, and which formed the basis of my report for 1897, are given below in full, together with the additional information which I have been able to obtain since writing the last report. Occasionally, when the context requires it, a brief abstract is given from the former report.

IDENTIFICATION AND DISTRIBUTION.

I. *Does the animal, known to our fishermen as the starfish, or five-finger, belong to one or to several species? (It is evident that, if there are two or more species, artificial or natural agents destructive to one may prove quite harmless to the others.)*

We have in Narragansett Bay four species of starfishes, out of the eight hundred or more which are known to occur the world over. They are:

The common starfish (Asterias Forbesii).
The purple starfish (Asterias vulgaris).
The blood starfish (Cribrella sanguinolenta).
The snake starfish (Ophiopholis aculeata).

The last two species are so distinctly different from each other, and from the first two, that there is no difficulty in identifying them. Neither species is harmful to the shell fisheries.

The common starfish and the related purple star vary so much with regard to color, shape of arms, size, number of species, etc., that the French naturalist, Perrier, has made five distinct species of Asterias to include those starfish along our coast, which, according to the American naturalists L. Agassiz, Stimpson, and Verrill, belong to two species only.

I have endeavored during the last year to ascertain whether some of these varieties were to be explained as a difference in sex, but I have been unable to discover any such relation, and am not able to distinguish males from females except by the sexual products.

II. *What is the geographical and bathymetrical distribution? (The reply to these questions will indicate the area subject or most liable to invasion.)*

Geographical distribution. (Only the first two species are considered in this report.) The purple star ranges from Labrador (probably further north) to Cape Hatteras, and is most common north of Cape Cod. The common star ranges from Maine to the Gulf of Mexico, and is the species most common south of Cape Cod.

Bathymetrical distribution. Purple star; high water to 208 fathoms. Common star; high water to 20 fathoms.

From the numerous dredging expeditions of the U. S. Fish Commission launches and the steamer "Fish Hawk", carried on last summer, it appears that in Narragansett Bay the purple starfish

(Asterias vulgaris) is practically restricted to the lower portion of the Bay, below Gould Island. Occasionally, of course, a specimen may be taken farther north. One specimen, for instance, was taken near Dyer's Island, among a thousand or more of the common species. I have never known a single specimen among the thousands of bushels of starfish captured on the oyster beds which are located in the upper half of the Bay. The common starfish, on the other hand, occurs in greater or less abundance everywhere from Fox Point to the mouth of the Bay, and is the only species that commits depredations upon our oyster beds. (The purple star would doubtless be destructive if it were present.) The starfish taken from the vicinity of the oyster grounds are, moreover, very similar to one another in appearance, as compared with those which may be collected in one locality at Woods Holl. At this station one haul of the mops may bring up stars which apparently belong to half a dozen quite different varieties.

There are other varieties differing from those found on our oyster beds, and from the purple starfish, which seem to be characteristic of certain localities. Thus, at the head of Buzzards Bay, at Ney's Neck, a large number of specimens of common star were collected, which were very similar to one another, but quite different from those found on our oyster grounds. They had very large coarse spines, and were of a bronze color. The specimens taken by the "Fish Hawk" in the waters south of Narragansett Bay (see other part of this report, p. 35) seem to constitute a variety ("maroon star") which occupies this area to the exclusion of other kinds of stars.

It is not known certainly whether each of these so-called varieties is an actual variety in the sense that the individuals breed true, or whether the peculiar appearance is due merely to the fact that the individual stars are bred and reared in a particular locality.

If it should prove to be true that the young of a certain variety, e. g., the maroon star, are always like the parent stars, no matter where they grow, we might be able to determine to what extent

the starfish are dispersed while in the free-swimming larval condition. We will refer to this question again in Chapter X.

MODE OF LIFE.

III. *What is the method of locomotion? (It is possible that some barrier might be arranged that would limit, if not prevent, invasion.)*

The starfish crawls or glides over submerged surfaces by means of the very numerous "suckers," or feet, which protrude from the furrows on the under side of the arms.

Small stars, one-half inch or less from tip to tip, are frequently seen, ventral side uppermost, moving along with their suckers reaching to the surface of the water. This performance can be carried on only when the water is very quiet, and is not often observed outside the aquarium. The buoyancy of the water and the great number of sucking feet enable the animal to crawl over the softest silt and the smoothest hard surfaces with ease, while the remarkable suppleness of the body enables it to get through incredibly small crevices. Beside this ordinary mode of locomotion, another peculiar method has been accredited to the starfish by many: namely, that of clinging together in great clusters and rolling along the bottom with the tide.

For the purpose of testing the ability of starfish to creep over soft surfaces, vaseline was smeared thickly on a vertical glass plate and on the under side of a horizontal glass plate. These plates were submerged in the aquarium with the starfish which measured two or three inches from tip to tip. The animals were observed to crawl over both these surfaces with no apparent difficulty. Paraffine was used in the same way and with the same result. It would appear, therefore, that submerged surfaces, though ever so soft or slippery, would not be effective barriers against the invasion of starfishes.

As was stated in the last report, starfishes will not crawl out of the water, nor even protrude an arm above the surface. They

will, however, move along over a surface covered with a very thin layer of water, even if it is not deep enough to cover the whole body. The animals are perfectly secure, therefore, in a disk of water as shallow as a soup plate, so long as the water does not flow over the edge. But if they are placed in an aquarium which is constantly overflowing, they will frequently crawl over the edge and down on the outside. No barrier, therefore, over which even a thin layer of water is flowing, would be effective.

IV. *Are the starfish which are reputed to appear in schools in any way different from those known to occur naturally in a particular locality?*

I have thus far not had an opportunity to examine the starfish reported to appear in schools.

V. *To or from what distance may starfish migrate?*

This is a problem which has a decidedly practical bearing, but we have as yet very little accurate data for its solution. I have been told by several oystermen that the starfishes sometimes suddenly appear in great numbers upon the oyster beds, and move over them at the rate of a quarter of a mile per day, more or less. It is generally understood, moreover, that there is some sort of a seasonal migration especially noticeable at the spring and fall, but the character and extent of this migration, if it really occurs, is unknown.

If a starfish crawled constantly in one direction, at the rate of six inches per minute, which is a fair rate for a medium sized specimen, it would travel about four miles in a month. At this rate starfish could go from one end of the Bay to the other in the course of the summer. But there is no good evidence that they do take such extended excursions. The fact that stars can be found all the year round in the upper part of the Bay, and on the oyster beds, shows that there is not a wholesale migration to any great distances. There are some other facts which seem to indicate

that the wanderings of these animals are rather limited in extent. Certain kinds of starfish which are common in one part of the Bay are not found, or are rare, in other parts. The purple star and "maroon star" do not migrate into the upper half of the Bay, although the purple star, at least, might live in these waters, as I have found by keeping them in confinement. The starfish in two neighboring parts of the Bay, namely, Mt. Hope Bay and Kickemuit river, do not seem to migrate back and forth, for those caught in Kickemuit river, during the past two years at least, were for the most part small, rarely measuring more than three inches from centre of disc to tip of arm, yet about a mile from the mouth of this river there have been great quantities of very large stars with arms four inches long or more. In Barrington river there seems to be a great preponderance of small stars about two and a half inches (arm) or less, which are of a reddish-brown color, and so are distinguishable from the average starfish caught in the vicinity of Nayatt. After the great freshet in the spring of 1888, the starfish in Kickemuit river nearly all perished, Mr. Bourne tells me, and did not become again troublesome for three or four years.

These facts, though they are not conclusive evidence, lead to the conjecture that there are natural barriers to the migrations of starfishes in our Bay. Some of these barriers may be: the depth of water, density of water, or a strip of barren bottom.

If the conjecture is correct, that the migrations of the starfish are confined to comparatively limited areas, the prospect of diminishing their numbers by a systematized effort is encouraging.

VI. *What animals are devoured by the starfish for food? (If the young starfish feed habitually upon certain animals, it is possible that the destruction of the latter will cause the former to perish.)*

Abstract. The starfish, especially when young, are exceedingly voracious feeders, prey upon oysters, clams, mussels, barnacles, various kinds of sea-snails (including oyster drills), worms and small crustacea, and, if slightly pressed by hunger, turn cannibal and prey upon smaller starfish.

It was found during the past summer that the starfish in Mt. Hope Bay and in the vicinity of Nayatt were feeding in great numbers upon a little bivalve which closely resembles a young quahog. This little animal, however, is not a young quahog, but an adult mollusc of another species—Mulinia lateralis. Fig. 1 represents a large specimen drawn natural size. The "Fish Hawk" found these animals to be exceedingly abundant during the last season in certain parts of the Bay.

Mussels are a favorite food of the stars, and doubtless many thousand bushels of mussels are devoured by them every season.

Indeed, some of the mussel beds have disappeared within the last few years, having been destroyed, probably, by the starfish. Unlike the oyster beds, the mussel beds are not protected from the onslaughts of the stars, and we can appreciate the extent of the damage to the mussels, if we imagine the condition of a bed of small oysters unprotected from the starfish for a single season.

In rearing the young stars for the purpose of studying their rate of growth, etc., I found them to be very fond of small clams and barnacles, as well as of young oysters. I will speak in more detail of the damage done to the young clams by the starfish in another chapter.

I have caught starfish in the act of devouring oyster drills, and believe it probable, therefore, that the drills, which are a serious menace to the oysters in some localities where the starfish are rare, are to some extent held in check by the stars.

VII. *What is the method of feeding?*

This question has been satisfactorily answered by Dr. Schiemenz, a German, and a brief review of the results of his work, as well as some of the current opinions on this topic, were given in the report of last year. The point of Schiemenz's results is as follows: The starfish grasp both valves of the shell fish, and by persistently exerting a constant, steady strain, finally fatigue the muscles holding the valves together so that they gap open slightly. Then the

stomach is protruded between the shells, and the soft body of the mollusc is digested. Frequently I have noticed that small animals are taken into the stomach through the mouth, which is able to stretch to a surprising extent. On one occasion I found, on cutting open a starfish, that it had swallowed a clam whose shell was so large that I could not push it back through the ring of bony plate which surrounds the mouth.

VIII. *At what season of the year do the starfish spawn? (If at a particular season, a special effort should be made to kill the animals before spawning, and thus destroy both stars and spawn.)*

I have attempted by two methods to determine the spawning season of the starfishes in the upper portion of our Bay and at Woods Holl. The first method consisted in examining a large number of adult starfish at intervals during the year, to see if they contained ripe eggs and milt. The second method consisted in dragging a fine silk " tow net " at surface of the water, to catch the free-swimming young.

Most of the adult starfishes examined were obtained through the kindness of the oystermen in Kickemuit river, Mt. Hope Bay, and the vicinity of Rocky Point. The observations on the condition of the eggs and sperm were begun in July, 1897. On the 19th and 22d of this month 630 stars were carefully examined, and the sizes of the specimens (taking always distance from mouth to tip of arm), and of the sexual glands, were tabulated. The specimens ranged from $1\frac{1}{4}$ to $3\frac{1}{2}$ inches (31 to 90 millimeters). Of these, fifteen specimens were found to contain eggs or sperm which was apparently ripe. In some, only one arm contained ripe products. None of these apparently ripe specimens were smaller than two inches. In the great majority of the specimens the sexual glands were small, less than one-half the length of the arm.

During the remainder of the summer, stars from these localities were frequently examined, and occasionally a specimen was found

with ripe eggs, but there was no general increase in the size of the glands.

On November 15 a lot of stars from Rocky Point were examined. They were nearly uniform in size, and measured about three inches. In about one half of these specimens the glands were half the length of the arm, but none were ripe. Among the seventy-five specimens, measuring approximately three inches, collected at the same place November 29, fourteen seemed to be nearly mature; the glands in forty-four of the others were half the length of the arm. The remainder had small and immature glands.

January 6, 1898, Rocky Point: About forty stars, $3\frac{1}{2}$ to 4 inches in length, were examined. Of these only four had sexual products which seemed to be nearly ripe, while the majority seemed less mature than in November.

January 7, Kickemuit river: Fifty stars, ranging between $2\frac{1}{2}$ and $3\frac{1}{2}$ inches (four specimens measured 4 inches). In twenty specimens the glands were considerably developed, but not nearly ripe. In the remaining thirty they were quite small.

January 15, Kickemuit river: Fifty stars, measuring from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches were examined. In general, there was, perhaps, a slight increase in size of glands, though in over thirty they were very small.

February 9, Rocky Point: 126 stars, measuring from $2\frac{1}{2}$ to 4 inches. In three specimens the sexual products were ripe; in ten, nearly ripe; in fifty-three, large and turning color, becoming slightly pink; in forty-seven, small, but showing signs of seasonal development; in twelve, very small.

February 12, Kickemuit river: Sixty-three specimens, measuring from 2 to $3\frac{1}{2}$ inches. In six the glands were large and beginning to show a pink color; thirty-nine showed seasonal development, while eighteen were very small.

March 4, Kickemuit river and Mt. Hope Bay: Thirty-nine specimens, $2\frac{1}{2}$ to $3\frac{1}{2}$ inches in length. One specimen was apparently quite ripe; twenty-six seemed nearly ripe; the glands in

seven were beginning to change color; in three, immature but showing seasonal development; in only two specimens were the glands very small.

March 7, Rocky Point: Ninety-nine specimens, measuring 2 to 3½ inches. Five specimens were apparently fully ripe; seventy-one specimens nearly ripe (very large glands); in twenty, the glands showed the pink color slightly; in two the glands were small, but showed seasonal development; only one specimen had very small glands.

It is evident that, during the latter part of January and throughout the month of February, there is a regular increase in the size of the sexual glands in nearly all the starfishes from Rocky Point, Mt. Hope Bay, and Kickemuit river. By the end of the first week in March, the great majority of the stars have the appearance of being nearly mature, while the remainder, except in a few specimens, show a distinct seasonal growth in the sexual glands. The stars are at this time beginning to look "fat," because of the increased size of these glands and of the digestive glands, usually called the "liver," which fill the arms.

April 5, Rocky Point: 197 specimens examined, varying in length from 2 to 4 inches. Of these, 137 had the appearance of being fully ripe; 32 were nearly ripe; in 20 the glands were beginning to show the pink color; in 9 they were smaller, but showed seasonal development; in one only were the glands very small.

April 13: Twenty-five specimens, out of a basketful from Mt. Hope Bay, were examined. All seemed to be ripe, and so the examination was not carried further.

Although at this time, i. e., during the first two weeks of April, the stars are all *apparently* ripe, they do not discharge the products for about two months. During this time they have the appearance of being extremely "fat."

On May 17, the stars were examined again in Kickemuit river and Mt. Hope Bay, and appeared very much as in April. They were, perhaps, more distended with spawn and milt, but had not yet discharged.

During the first four days of June, starfish from many localities in the upper portion of the Bay were examined on board the launch "Sagitta," engaged by the United States Fish Commission. The stars were, almost without exception, full of very ripe eggs and sperm, which were easily shaken loose in the water. Small specimens, measuring, in many instances, only an inch and a quarter, were fully ripe.*

The height of the spawning season occurred between this date, June 4, and June 16. From June 16 to June 28 the starfish examined in many localities, especially at Kickemuit and Rocky Point, had extruded most of their eggs, or sperm, but in some specimens the ripe spawn was found in one of the arms, or merely in the base of the arms, as though not quite all had been extruded. Specimens in which some ripe products were left were more frequent on the 16th than on the 21st, 22d, and 28th of the month, which indicates that the spawning season was rapidly drawing to a close.

Starfish examined in July, and occasionally during the rest of the summer, yielded the same results as those examined at the same season in 1897; most of the specimens had very small sexual glands, but some were found with products apparently ripe.

Young Stars. On the 22d of June, I searched carefully on the sea-weed and ell-grass in Kickemuit river for very young stars; not a single young star (under $\frac{1}{2}$ inch or more) could be found.

A week later, on the 29th of June, another careful search was made in the same locality, when I found countless numbers of very minute starfish, most of them about the size of the head of a pin. They were clinging by the dozen to every spear of ell-grass, and scattered diffusely through the branches of fluffy sea-weed, which is abundant in this locality. The larger of these little stars was probably not more than a few days old (since time of setting) as I afterward determined by watching the growth of those whose exact time of setting was known. Doubtless, therefore, the small

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* See Chapter on "age and size at sexual maturity."

stars were absent, and not overlooked, in the search on June 22. I feel sure, therefore, that in this locality the starfish first began to set, in considerable numbers, on June 28, or within a day or two of that date.

Free-swimming larval stars. The first attempt to capture the starfish in the free-swimming stage of their existence was made in the evening of June 27, at Kickemuit. The tow-net was dragged at the surface at intervals for two hours in the evening. The conditions of the weather were unfavorable, as I afterward learned, and for this reason no young starfish were caught. On the following morning, June 28, a great number of fry were found swimming at the surface of the water. From this date until July 16 they could be captured at any time, unless the conditions were particularly unfavorable. The few larvæ caught on July 16, however, were old, and all of them set in the aquarium during the next twelve hours. After this no more larvæ could be obtained, although the next few days were exceptionally favorable.

It is evident, therefore, that in Kickemuit river the season during which the starfish larvæ set in considerable numbers began about June 28 and ended about July 16, a period of a little less than three weeks. Allowing that the larvæ set three weeks after the spawn is laid (which is the period given by Ingersoll), we may conclude that the beginning of the spawning season was about June 7, and the end June 28, while the height of the season was the first, and possibly the second, week in June. From the observations of the sexual glands of the adults, it appeared that the greater part of the spawn was extruded during the 4th and the 16th of June. The facts, therefore, obtained by both of these methods agree very closely. Through the kindness of Dr. Seitaro Goto, of Tokyo, Japan, who worked in Mr. Agassiz's laboratory at Newport in 1895, I have obtained the following interesting data. For one or two days before the 15th of July, the larvæ had been very numerous. On the 15th they were decreasing in number and after the 20th of July none were found. At Newport in 1895,

therefore, the breeding season was nearly the same as that at the Kickemuit river in 1898.

At any time in the year a few starfishes may be found which contain ripe eggs and spermatozoa, but it is not known that these eggs are laid out of season. If they are, the chance of their becoming fertilized is small. Dr. Goto writes me that a similar phenomenon is seen in a Japanese species of sea-urchin. He is able to obtain ripe eggs and sperm, and to fertilize the eggs artificially, even in the midst of winter, though the species probably does not breed in these waters at that season.

Summary. To answer briefly the question asked at the beginning of this chapter, we may say: The starfish in the upper portion of the Bay, and probably throughout the Bay, have a short spawning season, which begins about the second week in June and continues for two or three weeks. The young fry begin to set during the last week in June, and continue to set until the middle of July. The fact that ripe starfishes may be obtained in very small numbers throughout the year is of no practical significance, for if such specimens lay their eggs out of season, the chances are comparatively slight of their being fertilized.

Observations were made at Woods Holl, from March to the end of the summer. It is rather difficult to interpret the results satisfactorily, for at no one period were more than a small proportion of the stars at Woods Holl ripe, or even approaching a ripe condition, and, on the other hand, a few ripe specimens could be found at any time. As a rule the sexual glands were very small, like those of the Narragansett Bay stars in mid-winter, and it was noticeable also that in such specimens the digestive glands were also unusually small. The latter condition I take to be an indication of poor nourishment, judging from the condition of poorly-fed stars kept in confinement, as compared with well-nourished specimens. I am inclined, therefore, to assign the failure to breed to the same cause.

In this connection I may observe that in the specimens kept over winter at Kickemuit, with very little to eat, the sexual glands

did not approach the ripe condition. An examination of the stars taken in February and March from Narragansett Bay shows that by this season of the year they are eating voraciously, shells, and even fragments of starfish, being found in their stomachs.

In some previous years the stars have bred in abundance at Woods Holl, but the notes on the time of breeding are somewhat puzzling, as they indicate that the time varies considerably.

IX. *What are the habits of the "fry" of free-swimming young? (The young of many marine animals, while far more abundant than the adults, are far more delicate and easier of extermination.)*

The ripe eggs of the starfish are minute spherical objects, measuring about one-tenth the diameter of the head of a small pin. They are discharged from the female through minute pores near the base of each arm, free, into the water, where they may become fertilized by the spermatozoa discharged from the male in a similar manner. Each egg, soon after it is fertilized, commences to undergo a long series of changes in form. During the first stages of development there is little or no increase in size, and the egg rests, like a minute grain of sand, upon the bottom. In the course of a few hours, however, the internal changes which have been taking place express themselves. Vibratile cilia appear in certain areas on the surface of the egg, which now begins to rotate, and soon rises from the bottom as a free-swimming larva. Soon after this the mouth and stomach are developed, and the creature takes in food and grows. The growth is rapid, and during the next three weeks, more or less, the larva increases its diameter about fifty times. Meanwhile various internal organs and several long arms, and other external features, are developed. The older fry are called brachiolaria, from the fact that they have so many long arms. One of these brachiolaria of the largest size is represented in Fig. 2, much magnified. The natural size is shown in Fig. 4, where two specimens are figured, one on either side of the bit of eel-grass. The animal swims by means of the

motile cilia, which are arranged in bands, represented by the heavy lines in the figure. They form a complicated pattern over the surface of the body, and extend out upon the arms. The body is quite transparent, and the tips of the arms, which are shaded in the figure, are light red. The larva represented in Fig. 2 is old, and would probably have set within twelve hours. Already the rudiment of the resulting starfish, the disc-shaped body at the bottom of the figure, can be seen within the brachiolarian. The five crenate lobes on the margin of the disc are the beginning of the five arms. The disc itself at this time is already somewhat opaque.

When the larva is about to "set" it attaches itself to some object, like a spear of eel-grass, by the suckers, shown at the top of the figure, and then a rapid transformation occurs. The whole superstructure above the disc collapses and becomes absorbed like the tail of a tadpole. In a few hours the brachiolarian has disappeared, and a starfish proper has taken its place.

Although the free-swimming larvæ have a considerable power of locomotion, and can swim from one side of a dish to the other in a few minutes, they can not, of course, make headway against the tidal currents, and are carried hither and thither with their ebb and flow.

Other extensive movements of the larvæ are executed in response to such changing conditions as those of light and temperature; at a certain time myriads of them are swimming at the surface of the water, and in twelve hours not one specimen can be found. The brachiolarian, like more lowly organized forms of living creatures, although it has no eyes, is exceedingly sensitive to light, being attracted to it sometimes, and again being repelled by it. According to my experience, they were found at the surface in greatest abundance on cloudy or misty days and nights, and were much more rare, or absent altogether, on bright clear days and moonlight nights. On the evening of June 27th, for instance, I skimmed the surface with the tow-net from nine until eleven o'clock, and not a single larval star was found, though

there were millions of the larvæ of the annelid worm Syllis, and other organisms. The night was clear, with bright moon, and the tide was rising. The next morning, June 28th, was cloudy, with some rain, and large numbers of the larvæ were taken in the nets, between 8.30 and 10 o'clock. In the evening of this day, between 9 and 11 o'clock, they were even more abundant than during the day. The evening was calm and cloudy, with a little rain. Afterward I met with the same experience on several occasions.

Another question in respect to the movements of the free-swimming larvæ is of practical importance, inasmuch as they are thousands of times more numerous than the adult stars. To what distances may the larvæ be carried by the tides and currents in our Bay? I cannot answer this question directly, but there are certain facts which have an inportant bearing upon it.

Although the purple stars (Asterias vulgaris) are common in the lower portion of the Bay in the vicinity of Newport and Seaconnet, they seem to be totally absent from the upper parts, although the adults, at least, can live in these waters. I have kept them for a long time in Kickemuit river. This would seem to indicate that the larvæ of the purple stars are not transported by the tides from the lower to the upper portion of the Bay. It may be, of course, that the larvæ, unlike the adults, cannot abide in the upper portion, or that the young stars, as soon as they can crawl, return to the southward unnoticed; this seems to me, however, to be improbable.

The distribution of some other marine animals whose habits are similar to those of the brachiolaria is of interest in this connection. At Waquoit, about ten miles northwest of Woods Holl, on the Vineyard Sound side, the water was fairly alive with the young of a certain species of jelly-fish, which could be taken from this locality in immense numbers at any time for several weeks during the spring. At Woods Holl, however, these specimens were comparatively rare.

Again, later in the summer, at Menemsha Bight, near Gay Head, another small jelly-fish was found in such great abundance that

every bucketful of water contained thousands of specimens, yet they were exceedingly rare, if present at all, at Woods Holl.

In the upper part of Buzzard's Bay, at Ney's Neck, the starfish probably bred in great numbers, judging from the appearance of the adults earlier in the spring, yet the larvæ were rarely caught at Woods Holl.

These facts, and others of the same nature, certainly suggest that the larval starfish may not be transported to great distances in the Bay by the tides.

X. *What is the duration of the larval period? (If an effort is to be made to destroy the larvæ, when must it be made?)*

The reply to this question has been given in detail, in chapter VIII, p. 48. Briefly stated, the larval period of an individual star is probably about three weeks. (The precise length of time could be ascertained only by keeping certain larvæ under observation and in normal conditions from the time the egg is fertilized until the larvæ set.) The period during which the larvæ may be found in the water extends from about the second week in June to the third week in July, according to the observations last year. There may be a slight variation from year to year, as in the case of other marine animals. The larvæ set in very great numbers about the 28th of June last year. An effort to destroy the larvæ would be more effective, therefore, during the last of June, when the spawning season is practically past and the setting has not begun.

XI. *What are the habits of the young starfish? (It is possible that the young starfish, like the young of many fish, tend to gather in schools. If so, the young might be killed off in thousands.)*

The data with reference to the habits of the young stars were collected at Kickemuit, where I was able to have a certain area along the shore under constant observation.

Up to the very time when the larvæ are ready to set, they swim freely in the water, and I have often caught larvæ in the tow-net

which set in the dish of water before I returned to the house-boat, *i. e.*, within an hour of the time they were caught. In this condition they attach themselves by their suckers (see Fig. 2) to any object they happen to strike, and cling to it with great tenacity, until the metamorphosis is completed. As the larvæ are borne along by the currents, the eel-grass, rock-weed, and especially the fluffy, branching sea-weed, naturally catch immense numbers of them. I think it would not be an exaggeration to say that on a single handful of sea-weed which I picked up about the first of July there were more than a thousand young stars. For the next three weeks they remain for the most part crawling about over this vegetation, gradually working down among the roots of the rock-weed, and on-to the large stones at the bottom. They grow rapidly during this time, but decrease in numbers, for they are bright and conspicuous objects for the small fishes. Nevtheless, they are exceedingly numerous for a long time. In order to obtain a definite expression of their abundance, I scooped up a large handful of the fluffy sea-weed, which, together with the water, about two-thirds filled a paper pail, and my friend Neal Bourne picked off from this 603 young stars. The average size was about that in Fig. 9. A cart-load of sea-weed taken out at this time would have destroyed millions of starfish.

By the first of August the fluffy, branching sea-weed, which bore so many young stars, was nearly all dead, and though the stars were still present in great numbers, upon the eel-grass, rock-weed, and stones covered with sea-moss, they were also frequently seen crawling along the muddy bottom.

By the 15th of August the eel-grass was overgrown and lodged by a luxuriant growth of Botrylus, a compound ascidian, which appears as dark gelatinous patches. The small stars were still numerous upon it, but were rather thin and poor. The greater portion of the stars had left the eel-grass, and were searching for food upon the stones and along the bottom; these were larger and better nourished than those which remained upon the eel-grass.

The small starfishes, such as live upon the eel-grass, are remarkably hardy in some respects. They will live for weeks and even months, in a small dish, without change of water, and with the minimum amount of food. During the first week in July I carried a number of free-swimming brachiolaria, like the one figured, to Providence, for further examination. They were carried in a glass one-quart butter jar, and, after one or two specimens were taken out, the jar was closed and left on my desk unopened during the rest of the summer. In a few days the larvæ had all set, and when I examined the dish again, on September 5th, it contained still a few live starfishes, which were, however, very small. Upon watching these specimens it was observed that the more enterprising individuals were eating their companions, and finally only one star remained. This one lived in the jar for weeks, but, unfortunately, I am not able to record the exact date of his death.

On the other hand, the same young starfishes, which can live so long without food or change of water, perish quickly if left out of the water, especially if the sun is shining. They cannot live, therefore, above the low-water mark, unless sheltered by a dense growth of vegetation. Large starfish can endure very much longer exposure, since their bulk prevents their drying so quickly.

On July 16th I made a special search for young stars, on the sea-weed, above the low-water mark. I found none, yet just below low-water mark they were excessively abundant. At the same time it was noticed that, above the line where the starfish were abundant, there was a thick set of one-year-old oysters, while below it the oysters were absent. The oysters set somewhat later in the season than the starfish, and the latter, therefore, are ready to prey upon the young oysters as soon as they appear. When, in addition to these facts, we take into account the extraordinary voracity of the young stars, their immense numbers, and their special fondness for oysters, we are led to conclude that one reason why a considerable set of oysters is so rarely obtained below low water is that they fall prey to the starfish. The oysters which

set above high water are comparatively safe, for when the tide leaves them uncovered they can endure for hours the direct heat of the sun, which would kill the young starfish in a few minutes.

While the starfish are living upon the eel-grass and sea-weed they are supplied with an abundance of food in the form of the young of marine worms, snails, and other animals, which, like the stars themselves, swim freely in the sea for a time, and then settle down upon any object with which they happen to come in contact. Throughout July the water at Kickemuit was teeming with minute free-swimming creatures, and, in the aquarium, the growth of the youngest stars could be greatly accelerated by feeding them the contents of the tow-net. During the last four days of June innumerable larvæ of a marine worm, Syllis (?), were swarming at the surface, and on July 11th millions of the young of one of the sea-snails, Littorina (?), were caught in the tow-nets.

The clam, also, is one of those unfortunate animals whose larvæ set at about the same time as the starfish, and in the same places. The starfish before they are three days old show a predilection for young clams, which apparently does not diminish so long as any clams remain. Fig. 3 was drawn from life last summer by Dr. J. L. Kellogg, and represents a characteristic scene in the marine tragedy.

In order to ascertain how fast the stars of the average size found upon the eel-grass would devour the young clams of average size, I placed one such star in a dish with fifty-six clams taken at random from the margin of a stone. The larger clams were about the length of one arm of the star, and they ranged from this length to one or two millimeters. The experiment was begun at 1:22 P. M., on July 18; at 5:40, P. M., two clams had been devoured, each about the length of the arm of the star, and during the evening a third was eaten. At eight o'clock the following morning five had been eaten; at nine o'clock, six; and, at 9:05, the seventh clam had been attacked. I was absent from the laboratory for the next four days, and returning on the 22d found, at 6, P. M., twenty-nine empty shells whose contents had been

eaten by the starfish. The starfish had grown considerably, and was eating faster than formerly, for on the next day thirty-nine empty shells were found, and on the day following this forty-six were empty, while ten more had disappeared altogether, having doubtless been devoured shell and all at some time during the week. To make sure that the clams were killed by the stars, and did not die from some other cause, a control dish of clams was kept, in which all the specimens lived. *In six days the one starfish devoured over fifty clams.* Both starfish and clams represented the average size at this season. I regret that I did not record the exact dimensions of the starfish at the beginning of the experiment. Fig. 11 shows about the size of the star at the end of the experiment, on July 25th.

When we recall how exceeding numerous the starfish are, and that they are found in the same localities with the young clams, the result of this experiment becomes the more significant. At this rate the six hundred specimens taken from the one netful of sea-weed would devour thirty thousand clams in six days. The starfish in a cart-load of sea-weed, if it contained two hundred small fork-loads, would have the capacity for destroying over six million clams in a week.

Summary: The starfish set for the most part during the last few days in June, and the first week in July, some as late as the 16th of July. They remain upon the sea-weed in immense numbers until about the first of August, when many of them are found upon the bottom. By the 15th of August the greater portion of the stars have left the sea-weed and taken to the bottom. The young stars do very great damage, not only to the young oysters, but to the young clams.

The destruction of the starfish by the hundreds of thousands could be effected by collecting and drying a few cart-loads of sea-weed taken below low-water mark, in the month of July. After the first week or two of July the collection of the seaweed would not do any injury to the clams.

XII. *What is the rate of growth up to sexual maturity?*

The observations and experiments bearing upon this question were made at the Kickemuit river, and these methods were adopted:

A. A large number of starfish were kept under constant observation and surrounded with natural conditions as far as possible.

B. Frequent observations were made upon the starfish in their natural environment.

C. Individual starfish were reared under various conditions, and their growth recorded from time to time.

D. Starfish which were regenerating lost parts were kept under various conditions, to determine the rate of growth and the rate of regeneration.

A and B. On June 29th a bunch of sea-weed, on which were hundreds of small stars, was placed in a car at the house-boat. All the stars were very small. The greater number were about the size of that in Fig. 5, but they ranged from the size shown in Fig. 4, just setting on the eel-grass, to that in Fig. 6.

On July 15th it was found that hundreds of stars had crawled through the wire netting, and were thickly scattered about on the under side of the car. Here they had found an abundance of small barnacles, which to all appearances they very much relished. After preserving a few specimens, to compare with those taken from the sea-weed, the rest of the stars were left unmolested upon the bottom of the car. The average size of the stars on the car was greater than the average of the larger specimens on the sea-weed. This was doubtless due to the fact that the former were better fed. A difference in shape was also striking, those on the car being more plump. Figures 7, 8, and 9 represent three specimens taken from the sea-weed on this date, and Fig. 10, one of the larger specimens (3 m. m. from mouth to tip of arm) from the car, all natural size. The measurements which follow are all taken from mouth to tip of arm.

On July 18th the stars showed a very appreciable growth. One

of the larger specimens, measuring 5 m. m., is represented natural size in Fig. 11.

On July 24th one of the largest stars measured 8 m. m., and was preserved. See Fig. 12.

On July 26th one could see an appreciable growth since the 24th, and the specimen shown in Fig. 13 measures 9 m. m. In eleven days (since July 15th), therefore, there has been an increase of three hundred per cent. in the length of the arm, which is equivalent to a much larger increase in bulk.

The stars were taken from the bottom and put inside the car on August 1st, and were fed with barnacles and small mussels. They had by this time eaten nearly all the barnacles on the bottom of the car, and were doubtless in want of food.

On August 2d the largest specimen measured 11 m. m., and is represented in Fig. 14. Those on the bottom, however, which had left the eel-grass, were larger, some of them approaching the size of those on the car.

On August 13th a box thickly covered with barnacles was split up and pieces put into the car. The starfish always preferred the under side of the boards, and the latter were therefore placed barnacle side down.

The stars on the eel-grass were examined on August 15th and the larger ones averaged about $2\frac{1}{2}$ m. m., or about the size of that in Fig. 9.

On August 18th the largest specimens measured slightly less than 18 m. m. (See Fig. 15.) This specimen was afterward kept in a dish without food, and will be referred to again.

On September 5th one of the largest specimens was 26 m. m. in length of arm. (Fig. 16.) Another specimen measured 27 m. m., and several measured 25 m. m. or more.

On September 26th the largest specimen measured 35 m. m., and is represented in Fig. 17.

On October 12th the largest specimen found was 42 m. m. (Fig. 18.)

On October 25th one specimen was found which measured 54

m. m., or about $2\frac{1}{4}$ inches (Fig. 19). This specimen was preserved. (The next largest was 51 m. m.) It is shown in Fig. 19 and is the largest star reared in captivity. It was almost exactly four months old, having set about the 28th of June. The sexual glands were more highly developed than usual even for larger stars at this season.

From this date to November 11th there was no growth, but apparently a slight decrease.

The following gives in brief the measurements of some of the largest stars found upon the car during the summer and fall. The asterisk * indicates that the specimen was not returned to the car, so that a smaller specimen was recorded on the next date.

July 15.	*July 18.*	*July 24.*	*July 26.*	*August 2.*	*August 18.*
3	5*	8*	9	11	18

September 5,	*September 26.*	*October 12.*	*October 25.*	*November 5.*
27	35	42	54*	.....
26	35	40	51	45
26	34	40	50	44
25	33	38	48	43
25	33	36	45	43
25	31	35	45	43
24	30	35	44	42
24	30	......	......	40
24	......	......	......	......
23	......	......	......	......

On September 5th a number of specimens (nineteen in all) were picked out and placed by themselves in another car, so that I might be sure to measure the same individuals on succeeding days. These were measured on six occasions, with the following results :

Sept. 5.	*Sept. 26.*	*Oct. 12.*	*Oct. 25.*	*Nov. 5.*	*Nov. 11.*
24	35	40	47	46	41 (?)
24	31	35	40	38	41
20	30	35	38	38	40

Sept. 5.	*Sept. 26.*	*Oct. 12.*	*Oct. 25.*	*Nov. 5.*	*Nov. 11.*
19	29	34	38	38	39
19	29	33	38	38	38
19	28	32	37	38	38
18	28	32	36	38	36
18	28	31	36	37	36
18	27	31	36	37	35
18	26	30	36	37	35
17	26	30	35	37	35
16	26	30	35	37	35
16	25	29	35	34	35
16	25	29	35	35	35
15	24	28	34	33	34
15	23	28	32	33	34
15	21	27	30	32	33
14	21	25	30	32	31
12	21	.....	29	31	31

It will be noticed that among these specimens, as well as among those in the original car, given in the first table, there is rarely any evidence of growth after October 25th, but there is rather a slight decrease in size. On each occasion the measurements were made without referring to those of the preceding date, so that no personal prejudice might enter the results. For the most part the figures indicate a fairly uniform rate of growth among the different stars. In interpreting these figures, there is one factor which is to be taken into consideration, namely: that starfish over 20 m. m. (sometimes less) are able to contract and expand, so that two careful measurements, taken within a few minutes of each other, may vary as much as one or two millimeters. The measurements in the last three columns, therefore, indicate that the starfish in the car were of about the same size on November 11th as on October 25th. The first measurement (41 m. m.) on the bottom of the opposite page, under November 11th, is doubtless an error.

It may be inferred, from what has already been said, that at

any time during the summer, after the stars are all set, there is a great difference in size among them. To illustrate this point, I arranged on August 18th a series of specimens taken from the car and from the sea-weed, and photographed them at natural size, by laying them down on the sensitive paper (with a thin transparent film between), and then exposing. The variation in size is shown in Fig. 20, the first five specimens having been taken from the car and the last five from the sea-weed. This variation in size is without doubt due much more to the difference in the amount of food than to the difference in age. The following experiments on the rate of growth of individual starfish support this view.

C. Rate of growth of individual starfishes kept under various conditions. The starfish which was the largest of those in the car on August 18th (compare Fig. 15) was kept in a dish with only a few very small barnacles for food. When taken from the car it measured 18 m. m.; slightly more when fully expanded. On September 25th it measured 18 m. m., showing no growth. On September 26th, thirty-nine days after it was taken from the car, it measured between fifteen and sixteen m. m. In the absence of food, therefore, it had lived and apparently was in perfect health, but had probably diminished somewhat in length, as well as in bulk. (Some allowance must of course be made for the contraction and expansion, as mentioned before.) During this time several of the stars, smaller than this one, remained in the car and grew to the length of 35 m. m. (Fig. 17.)

A small starfish which was caught in the tow, and set on June 28th, was kept in the dish with many others until June 23d. On this date it was placed in a small dish by itself and fed with small clams and barnacles. Fig. 21 shows the growth of this specimen: A. 2 m. m., July 23d; B, 4 m. m., August 13th; C, 4½ m. m., August 18th; D, 5 m. m., September 6th. On September 6th it was transferred to a car where there was an abundance of small barnacles. Fig. 21, E (12 m. m.), represents size on September 26th; F, 21 m. m., on October 12th; G, 30 m. m., on November 5.

As a control to this experiment, several starfish, which also set on June 28th, were kept with a minimum amount of food. One of these, photographed at natural size on September 6th, is shown in Fig. 22 A, while the largest star in the car (with plenty of food) is represented in Fig. 22 B (27 m. m.). The specimen figured in A is thirty-nine days old, and that in B is within a day or two of that age.

The next experiment (illustrated by Fig. 23) on the growth of stars was as follows: On August 3d two stars of average size were taken from the original car and placed in another car with a bunch of mussels.

On August 3d (1) = 7 m. m. Fig. A.

On August 16th (2) = $10\frac{1}{2}$ m. m. Fig. A′.

During this time the stars had little or no food, since they could not, or would not, eat the mussels. On August 15th a lot of barnacles were placed in this car, and by September 5th the results of the new food were evident enough:

Sept. 5: (1) = 15 m. m., Fig. C (one arm was torn off in measuring). (2) = 19 m. m., Fig. C′.

Sept. 26: (1) = 28 m. m., Fig. D (new arm 10 m. m. measured from mouth, growth of 7 m. m.) (2) = 29 m. m., Fig. D′.

Oct. 12: (1) = 36 m. m., Fig. E (regenerating arm, 20 m. m., from mouth, growth of 17 m. m.) (2) = 41 m. m., Fig. E′.

From August 3d to August 16th, while these specimens were not growing at all, those in the car grew about 6 m. m. These two specimens afterward, however, having more food and no interference in eating it, made up this difference, and by September 26th had grown as much as those in the original car.

One interesting point which is brought out by the experiment is that a star which is regenerating an arm may grow as fast as a complete star. Compare next experiment.

C. Rate of growth and rate of regeneration. The starfish, like the lobster and many crabs, has the habit of dropping off an arm which has been mutilated, and of regenerating a new one. Unless the arm is mutilated or some other shock administered, one may

sometimes tear a star in two by pulling on the arms, while the latter still remain on the fragments of the disc. On the other hand, if the suckers are cut off from one arm, or the arm is crushed or cut several times, it will usually drop off, always at the same point near the disc, taking the sexual glands with it.

On the 26th of September five of the larger stars in the original car were deprived of the arm opposite the "eye," or madreporic plate, and then placed in a car with barnacles for food. The subsequent measurements show that they kept on eating and growing at about the usual rate, like the specimen similarly treated in the last experiment described. The measurements are given in tabulated form below, the first measurement indicating the length of the longest arm.

	Sept. 26.		*Oct. 12.*		*Oct. 25.*		*Nov. 5.*		*Nov. 21.*	
		New Growth.		New Growth.		New Growth.		New Growth.		New Growth.
A	32	0	36	3	42	7	41	11	40	12
B	30	0	35	3	38	7	41	12	40	11
C	28	0	30	3	35	7	38	10	38	12
D	27	0	29	3	30	6	35	9	38	11
E	25	0	28	3	..	..	34	7	35	9

A comparison of the table with that on page 61 shows that these stars, which are regenerating an arm, grew at about the same rate as the complete stars during the same period. The rate of regeneration was also about the same as the rate of growth in the original arms, except that toward the last the new members grew in some cases somewhat more rapidly.

Another experiment was made, similar to the above, except that two arms were taken off instead of only one, and the stars were younger at the beginning. The stars were at first all about 12 m. m. The eight detached arms were put in the car also, and on September 10th, twenty-six days after they were detached, five were still alive and apparently in good health, but had neither grown nor shown any sign of regeneration. One is figured natural size in Fig. 24 B.

The growth of these specimens is tabulated below. (Measurements were made from mouth to tip of new arm, but figures in table indicate merely new growth, and are derived by subtracting 3 m. m. from original figures.)

	Aug. 15.	Sept. 5.			Sept. 26.				Oct. 12.				Oct. 26.				Nov. 5.			
	Longest arm.	Longest arm.	1st Short arm.	2d short arm.	Longest arm.	1st Short arm.	2d Short arm.	Newest arm.	Longest arm.	1st Short arm.	2d Short arm.	Newest arm.	Longest arm.	1st Short arm.	2d Short arm.	Newest arm.	Longest arm.	1st Short arm.	2d Short arm.	Newest arm.
A........	12 (?)[1]	22	..	8	34	18	17	..	42	32	30	..	..	..	..	..	..	..	..	..
B........	12 (?)	20	..	7	30	17	17	..	36	26	26	..	..	..	..	..	43	31	31	..
C........	12 (?)	18	..	5	25	9[2]	9[3]	..	37	16	15	..	..	..	..	..	40	24	24	..
D........	12 (?)	18	..	5	23	14	12	8[4]	32	22	20	13	35	23	23	17	34	27	27	20

[1] It was intended at first to keep account only of rate of regeneration, and so four stars were picked out, of about the same size, and one only was measured. This was 12 mm. The others may have been one or two millimeters larger or smaller. The growth of this specimen and the size of the single arm alone, on September 26, are given in diagram Fig. 24, *A* and *B* respectively.

[2] One detached arm still alive—measures 7 mm.

[3] Tips cut off and arm slit on September 15. The longest arm was then 22 mm., and the regenerating arms 15 and 10 mm. respectively.

[4] Arm broken off, probably by handling, on September 5.

This experiment shows conclusively that when even two arms are lost the growth of the starfish is not necessarily arrested or the rate of growth diminished. The rate of growth in the new arms was greater than in the original arms, and there was a tendency, therefore, for all to become ultimately of the same length (Table D, October 12 to November 5).

Summary: The results show clearly that within very broad limits it is impossible to tell the age of a starfish from its size. Starfishes of all ages are able to live for months with very little or no food. The rate of growth depends directly upon the amount of food eaten. Starfishes which are regenerating one, or even

two arms, may, under ordinary circumstances, grow as rapidly as complete stars. The growth of the new arms, in the starfish experimented upon, was slightly more rapid than that of the original arms, showing a tendency in the organism to return to the original length. In four months from time of setting, some of the larger stars kept in the cars under favorable circumstances attained a length of from 50 to 54 mm., or 2 to $2\frac{1}{8}$ inches, measured from mouth to tip of arm. This is more than twice the length of many of the stars which were found just before the beginning of the breeding season, and which were therefore at least nearly a year old.

Allowing a moderate amount of growth during the winter and spring months, of 10 to 15 mm. (the amount of increase attained in one full month preceding October 12), the larger year-old starfish in the early summer would be about 65 millimeters, or $2\frac{1}{2}$ inches, in length, which is about the length of the greater number of stars taken on the mops in the Kickemuit River during the summer. (Fig. 19, a; 19, b.)

XIV. *What is the size and age at sexual maturity?*

Among the starfish caught in various parts of the Bay on June 2, 3, and 4, several specimens only $1\frac{1}{4}$ inches, or 32 mm., were found to be very full of sexual products. This size was attained by many of the starfish reared in the car on September 26, about three months from time of setting. See table on page 60. Great numbers of stars, measuring about 2 inches, or 50 millimeters, were found ripe the first week of June. This was the size of several specimens in the car on October 25, which were not more than four months old, and whose sexual glands were well developed. In other words, a large number of the starfish reared in the car were by the end of October as large as a great many which were sexually mature in June. Moreover, it was rare to find a specimen of this size on the first of June which was not full of ripe eggs which were laid later, as the empty starfish caught in July showed. It is an obvious conclusion, therefore, that, with fairly

good opportunities to obtain food, the starfish becomes sexually mature in less than one year, and that those hatched one season breed the next.

In his monograph on North American starfishes, Alexander Agassiz gives his views with reference to the rate of growth of the starfish in the following words: (The figures referred to represent specimens, all of them smaller than that in our Fig. 9, of a star about two weeks old raised in the car.)

"The young starfishes figured on this plate (Pl. VIII) were all found attached to roots of Laminaria, thrown up on the beaches, in the neighborhood, after a storm; and from their different stages of growth, as compared with the oldest starfish raised from a Brachiolaria (Pl. VI. Fig. 11) specimens of which were also found upon these roots, it is probable that the sizes here figured are one (Fig. 1), two (Fig. 8), and three (Fig. 10) years old. A considerable number of specimens were picked up in this way, and they could all be arranged into very distinct groups, representing the starfishes of the present and two previous seasons. There seemed to be no gradation from one group to another, such as we have among the young sea urchins, which, in consequence of their manner of breeding during the whole year, form series, the relations of which it is impossible to determine. In this connection I would say, that by arranging the starfishes found upon our rocks into series according to their size, we are able to obtain a rough estimate of the number of years required by them to attain their full development; this I presume to be somewhere about fourteen years.* They begin to spawn before that time, as specimens have been successfully fecundated which evidently were not more than six or seven years old. It is during the fourth year that the rate of growth seems to be most rapid. A young starfish, measuring one and a half inches across the arms, was kept, during five months, alive in Mr. Glen's tank at the museum, and during that space of time it grew to three inches."

It will readily be seen that my observations do not at all agree with those of Agassiz. I found no difficulty in obtaining all possible gradations in size among the stars in the late summer, and the stars represented by Agassiz as one, two, and three years old respectively, more nearly correspond with those raised in cars when they were one, two, and three *weeks* old.

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* For an account of the method adopted by Professor Agassiz for ascertaining the age of many of our marine animals, see Proceed. Essex Inst., 1863, p. 252.

XV. *What are the natural enemies of the starfish?*

The destructive agents and natural enemies referred to in the last report were cold and fresh water, various fishes which feed upon the larvæ, gulls and crows, and parasites.

Some of the specimens which were being attacked by the parasite frequently found in the fall of 1897 were kept over winter, and by spring the disease had disappeared. The effects of the disease were visible, however, in some cases. In one starfish an arm was entirely eaten through, about $\frac{3}{4}$ inch from the tip, but was not thrown off. The stump healed over, and the star was kept throughout the year and is probably still alive. It showed almost no trace of regeneration, probably from the fact that food was rarely taken by the specimen.

The enemy which is doubtless the most destructive to the starfish is the menhaden. In an article on the "Food of the Menhaden," published in the United States Fish Commission Bulletin, XIII, 1893, Dr. James I. Peck showed that this fish feeds exclusively upon the minute organisms which swim or float free in the water. The open mouth of the menhaden has an area of about one square inch, and as the fish swims through the water with open mouth and gill covers raised, a considerable column of water is passed through the mouth every minute (estimated by Dr. Peck at about seven gallons). The gillrakers strain the water, and the organisms which are not too minute are caught in the mouth and swallowed. The starfish larvæ of even small sizes are far too large to pass through the gillrakers. Numerous schools of menhaden feed in our Bay during the season when the starfish larvæ are swimming at the surface, and undoubtedly destroy them by thousands of millions.

After the stars are set they are no longer in danger of being destroyed by the menhaden, but for several weeks are bright conspicuous objects upon the seaweed and eel-grass for eels and many small fishes to feed upon.

XVI. *Is the popular idea that the dismembered fragments of a starfish will regenerate new starfish founded on fact?*

This idea is commonly held, and is apparently founded on the fact that in nearly every lot of stars brought up in the dredges or on the mops a considerable percentage of stars may be found which are regenerating lost parts. Frequently two, three, or even four arms are being regenerated, and these are much smaller than the original arms. Upon careful examination and inquiry into the extent of this regeneration, I have never found a well authenticated case among our species of stars in which part of the disc was being regenerated, except those reared with great care in the aquarium. With this point in view, I have examined a large number of regenerating stars caught in their natural haunts, some of them reported to be regenerating part of the disc, but invariably the regeneration was limited to the arm. I have, however, made a few experiments in the aquarium and in the cars, which have a bearing upon this question of regeneration.

The fact that a mutilated arm is frequently loosened and dropped off at a particular point near the base, and the rate of regeneration of specimens which have thus lost one or two arms, are recorded in a previous chapter, page 63.

All the arms may be pulled off, and, if the star is protected and fed, all will generate. Such a specimen is sketched in Fig. 25. This specimen was kept, after the operation, in a glass dish with frequent changes of water, and was fed upon the soft parts of crabs, etc. The regeneration was slow as compared with that given in the previous tables, the new growth shown in the figure (which is natural size) requiring about five or six weeks, probably owing to the comparatively small amount of food taken.

Since a mutilated arm drops off from the disc so readily, the latter nearly always remains intact, and in ordinary cases, therefore, if two stars were to result from one, one of them must regenerate from a single arm. I have several times kept single arms for a long time in the aquarium or cars, but have never seen any

trace of regeneration in them. On May 11 several arms were taken off at the usual line of detachment, and kept alive in the aquarium until June 9, when they showed no sign of regeneration. One of these was still alive on June 25, and at that time was apparently enjoying good health, and would turn over if put on its back. It had lived, therefore, for over six weeks, but showed no sign of regeneration.

Another experiment was started on August 15; two arms were taken off from each of four specimens. The rate of regeneration of these specimens is given in the tables on page 65. On September 10, nearly three weeks afterward, five of the single arms were found alive, but showed no regeneration. On September 5 the new growth in the arms regenerating from the disc was from 8 to 5 mm. On September 26, six weeks after the operation, one of the single arms was found alive (7 mm.) It had not shown any traces of regenerating a new arm, although it had healed. This arm is represented natural size in Fig. 24, B, and the new growth which took place on one of the stars from which these arms were detached is shown in Fig. 24, A. Similar experiments were tried last year with the same result. In a recent article by Miss Helen Dean King, in Roux' Archiv, it is stated that single arms were kept alive for two weeks, but never showed signs of regeneration.

Several experiments were carried on to determine what regeneration would take place if the disc were cut through. On May 11, nineteen specimens about $2\frac{1}{2}$ inches in length were treated in the following manner: Two arms were pulled off, and at the base of one of the arms a piece was cut out from the top of the disc in the manner shown in Fig. 26. These specimens were placed in a large car at Woods Hole without food (except what could be carried in the water). On June 9 there was a trace of regeneration in some of the arms. On June 25, a little more than six weeks after the operation, all the arms were growing out anew, and varied from a mere trace of a new arm with the terminal eye-spot (which always shows first) to arms $\frac{1}{4}$ inches (about 7 mm.) long. This experiment shows two things: that the new arm will re-

generate if a portion of the disc is absent, and that the rate of regeneration, like the rate of growth, in normal specimens, is dependent upon the nourishment, for, while the new growth in these cars was only 7 mm. in six weeks, those which were well fed at Kickemuit gained a new growth of from 13 to 18 mm. in the same time. See page 65.

Other experiments were tried, to determine what regeneration would take place if the whole starfish were cut through in various ways, while the arms were left in place. It will be seen that the results were not always the same.

In the summer of 1897 several stars about $2\frac{1}{2}$ inches in length were cut through so as to leave three arms and part of the disc on one piece, and two arms and part of the disc on the other. The smaller pieces perished, but the larger ones lived for several weeks and showed no sign of regeneration. All but one were destroyed by other starfishes, which got into their compartment of the car by accident. The remaining fragment, consisting of three arms and part of the disc, lived several months after the operation and did not regenerate.

On May May 11, 1898, several stars about one inch long were cut as in Fig. 27. One arm was pulled off and the disc then cut in two, leaving two arms with a part of disc and madreporic plate on one piece (=A), and two arms and part of disc on the other piece (=B.) The fate of the single arm has been already considered, page 70. On June 9 all the pieces were alive. In the piece marked A (*i. e.* having madreporic plate) a trace of a new arm arm was visible on the side toward the lost arm, but in no other place. The pieces marked B showed no regeneration at all. On June 25, six and a half weeks after the operation, the condition was as follows: All these parts of specimen 1 were alive. The fate of the single arm is mentioned on the previous page. The piece (A) with madreporic plate is sketched from the lower side in Fig. 28. Two arms were well started, and one minute arm was growing out between them. In the other piece (B) of this specimen, the wound was completely healed, but there was no visible

trace of any new arms. Of specimen 2 only one piece (A) was alive. From the stump of the old arm a very small new arm appeared—no trace of any other. The two pieces A and B of specimen 3 were alive and healthy. In A two very small arms were visible (one could be seen only with the help of a hand lens) near together, and on one side of the cut surface; on the other side there was a trace of another arm, indicated by an eye spot. B had healed up, but showed no trace whatever of regenerating arms. Of the fourth specimen piece A was found alive with two very minute regenerating arms. These specimens had very little food, and it is hardly necessary to remark that they grew very little or not at all.

On September 5, 1898, another experiment, similar to the last one, was commenced at Kickemuit River. Eight specimens were taken from those reared in the car, and cut in two in the manner shown in Fig. 29, leaving two arms and the madreporic plate on one piece, and three arms and part of the plate on the other. The pieces of the latter sort died in a short time, and the following tabulated data refer to the pieces having two arms and the plate ("eye"). At the beginning of the experiment the specimens measured in millimeters, 23, 21, 21, 20, 19, 18, 18, 18.

September 26th. (Three weeks after the operation.)

A	20 mm., bore trace of two new arms.
B	18 mm., two new arms (preserved) unhealthy.
C	18 mm., one new arm, 2 mm.
D	Crushed.
E	20 mm., healthy—no trace of another arm.
F	Overlooked. See next, October 12.

October 12th.

A	(?)	23	mm.,	two very small arms.
C		20	"	two arms, one smaller than the other.
E	(?)	22	"	no trace of regeneration.
F		21	"	one arm.
				(all healthy.)

October 25th.

C	20	(?)	two arm 8-10 mm., no trace of other.
E	22		no trace of regeneration.
F	21 / 20	(?)	one arm, 6 mm.; no trace of another.

November 5th.

A	25	mm.,	two new arms, 2 mm. each.
C	21	"	two new arms, 9-10 mm., no trace of other.
E	22	"	one new arm directly in middle, 1 mm. long.
F	19	(?)	one arm, $4\frac{1}{2}$ mm., no trace of rest.

November 11th. (Fig. 30.)

A	23	mm.,	two small arms, about 3 mm.
C	21	"	two small arms, 10 and 12.
E	21	"	one arm, $1\frac{1}{2}$ mm., directly in middle.
F	20	"	one arm, 6 mm.
			(no trace of other arms in any.)

Some other experiments of a similar kind performed upon young stars about the first of August yielded essentially the same results, with this exception: that out of the seven pieces which lived until September 5, four were those without madreporic plate, and three of these were regenerating new arms. Miss King, whose recent article has been already referred to, seems to have had better success than I, and says that from each of the pieces of a star cut in two a new star may be formed by regeneration.

That the madreporic plate is not essential to the life of the star-fish, at least for a very long time, is shown by another experiment. This organ was removed from five large stars on June 14, and on November 5 one of them was alive and healthy, but had not regenerated the lost structure. The madreporic plate was wanting in one specimen caught at Woods Hole on April 4. Another specimen was taken which had an accessory madreporic plate, which was not, however, connected with the stone canal. In the last report, I mentioned an experiment in which this body was extirpated and regenerated before the end of the season.

Summary: In every known case of regenerating starfish caught on the mops and in dredges, the new growth is limited to the arms. The arms are readily loosened and cast off when injured, but almost certainly do not produce new stars, as is shown by the experiment in which single arms have been kept for six weeks without trace of regenerating, and by the fact that single arms regenerating the rest of the stars have never been found among this species of star (they are common in some foreign species). Starfish which have been cut in two behave differently in different cases. They may live for a long time without regenerating the remaining arms to the slightest degree; they may show no sign of regeneration for several weeks, and then regenerate one or more arms; they may soon regenerate only one or two of the arms when three are required to complete the original form of the body. The rate of regeneration and perhaps the possibility of regeneration are dependent on the food supply, like the rate of growth. It is probably possible for two or more complete stars to result from one, but in many experiments in which the stars were carefully protected this result has not been obtained by me. The probability of this result occurring when stars are torn apart and thrown overboard is doubtless very slight, for, as the experiments show, such stars have difficulty in obtaining food, and are especially liable to injury and to destruction by other stars or enemies of various kinds.

XVII. *What are the artificial methods of destruction now in use in Rhode Island or elsewhere?*

These methods were given in the last report.

The starfish become easily entangled in the mops, not only because they are rigid and covered with spines, but because the little forceps (pedicellaria) thickly scattered over the surface of the body catch hold of the threads of the mop. If one presses the upper surface of a live starfish against the back of his hand, he will find that these pedicellaria grasp the hairs on the hand tightly, and will sustain the whole weight of the starfish.

EXPLANATION OF FIGURES.

Fig. 1. Mulinia lateralis, gray, natural size.

Fig. 2. Larva of starfish, nearly ready to set, in side view; dark bands show the position of the vibratile cilia; intestine and stomach shaded; five lobes at the lower portion of figure are the beginning of the five arms. From life, much magnified.

Fig. 3. Starfish about two days old, devouring clams. Outlines of the stomach of the starfish can be seen through the transparent shell of the clam. Drawn from life by Dr. J. L. Kellogg.

Fig. 4. Piece of eel-grass with starfish larvæ just undergoing their transformation; two specimens of larvæ at the sides. Natural size.

Figs. 5 to 8. Small specimens of starfish from seaweed about the first of July. Natural size.

Fig. 9. Shows size of average star found upon the eel-grass and seaweed on July 15. Natural size.

Fig. 10. Large specimen from car, July 15. Natural size, 3 mm.

Fig. 11. From car, July 18, large specimen, 5 mm. Natural size.

Fig. 12. From car, July 24, large specimen, 8 mm. Natural size.

Fig. 13. From car, July 26, large specimen, 9 mm. Natural size.

Fig. 14. From car, August 2, large specimen, 11 mm. Natural size.

Fig. 15. From car, August 18, large specimen, 18 mm. Natural size.

Fig. 16. From car, September 5, large specimen, 24 mm. Natural size.

Fig. 17. From car, September 26, large specimen, 35 mm. Natural size.

Fig. 18. From car, October 12, large specimen, 42 mm. Natural size.

Fig. 19. From car, October 25, largest specimen, 54 mm. Natural size.

Fig. 20. Series of starfish taken on August 18, showing varia-

tion in size; first 9 specimens from car, last 4 from eel-grass. Natural size.

Fig. 21. Shows growth of single specimen collected as a larva and set June 28. A, July 23, 2 mm.; B, August 13, 4 mm.; C, August 18, $4\frac{1}{2}$ mm.; D, September 5, 5 mm.; E, September 26, 12 mm.; F, October 12, 21 mm.; G. November 5, 30 mm. Natural size. See page 62.

Fig. 22. A, starfish set June 28. Kept alive in dish, and drawn natural size. September 5 ($5\frac{1}{2}$ weeks); B, from car, September 5, within a day or two of the age of A (page 63). Both natural size.

Fig. 23. Shows rate of growth in two stars, A, B, etc., and A′, B′, etc.; A and A′, August 3, 7 and $10\frac{1}{2}$ mm.; B and B′, August 16, 7 and $10\frac{1}{2}$ mm.; C and C′, September 5, 15 and 19 mm. (one arm pulled off from C); D and D′, September 26, 28 mm. (new arm 10 mm.), and 29 mm.; E and E′, October 12; E. 36 mm. (new arm 20 mm.); E′, 40 mm. Natural size. See page 63.

Fig. 24. A, rate of growth and of regeneration; I, August 15; II, September 5; III, September 26; IV, October 12; B, single arm alive, from August 15 to September 26. Natural size. See pages 64 and 70.

Fig. 25. Star regenerating five arms from ventral side. Natural size. See page 69.

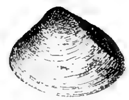
Fig. 26. Showing manner of cutting the stars in the experiment described on page 70.

Fig. 27. Showing manner of cutting the stars in the experiment described on page 71.

Fig. 28. Showing the regeneration of the arms in the experiment described on page 71; a portion of the disc regenerating three arms. Natural size.

Fig. 29. Showing the manner of cutting the stars in the experiment described on page 72. Natural size.

Fig. 30. The result of one of the regeneration experiments described on pages 72 and 73; one or two arms regenerating from a part of the disc. Natural size.



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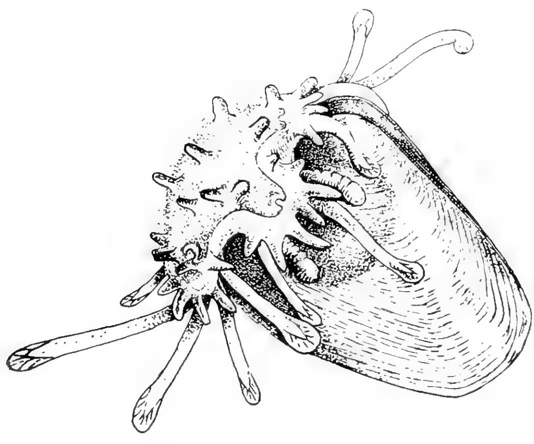

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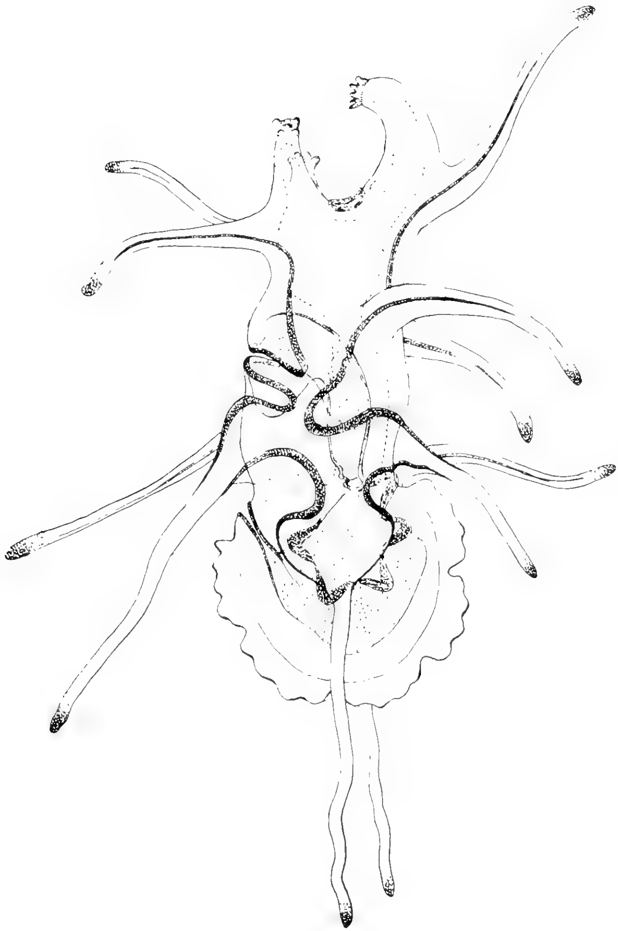

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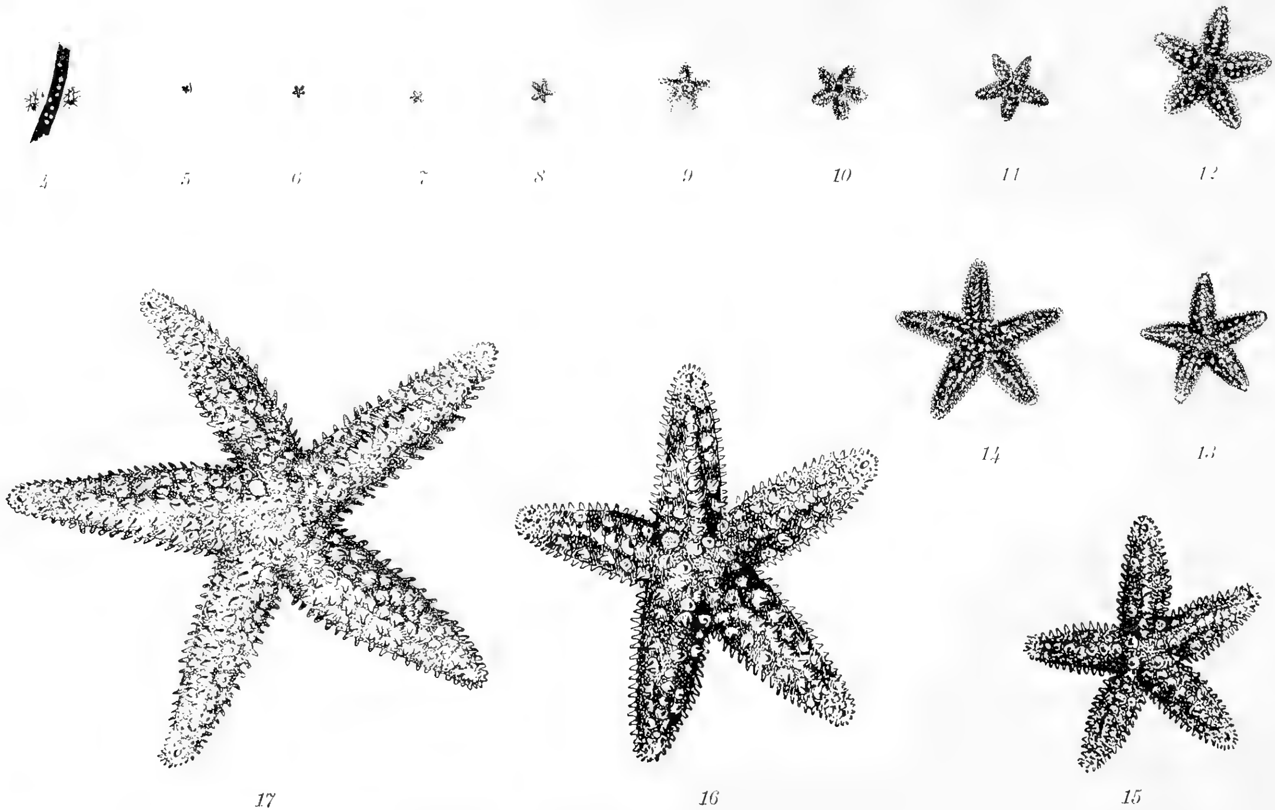

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Fig 20.

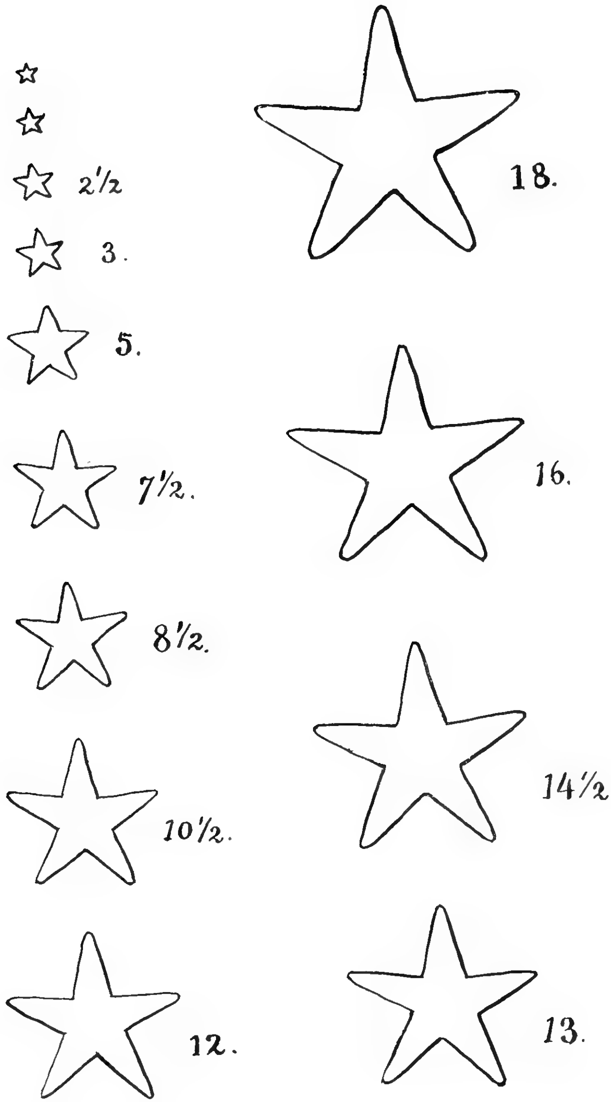
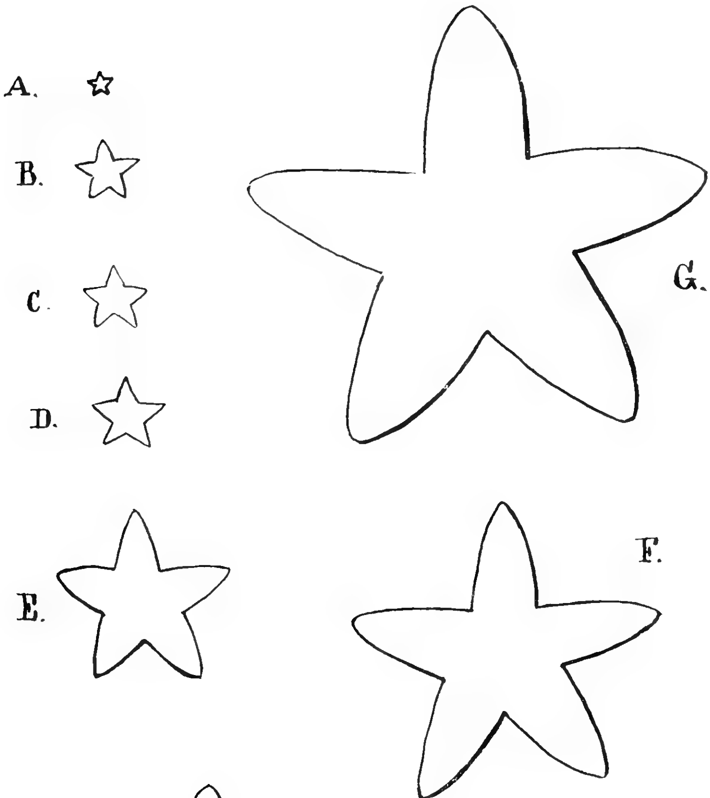


Fig 21.



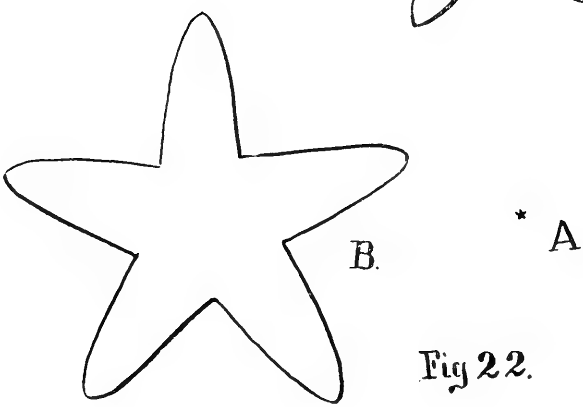


Fig 22.

Fig 23.

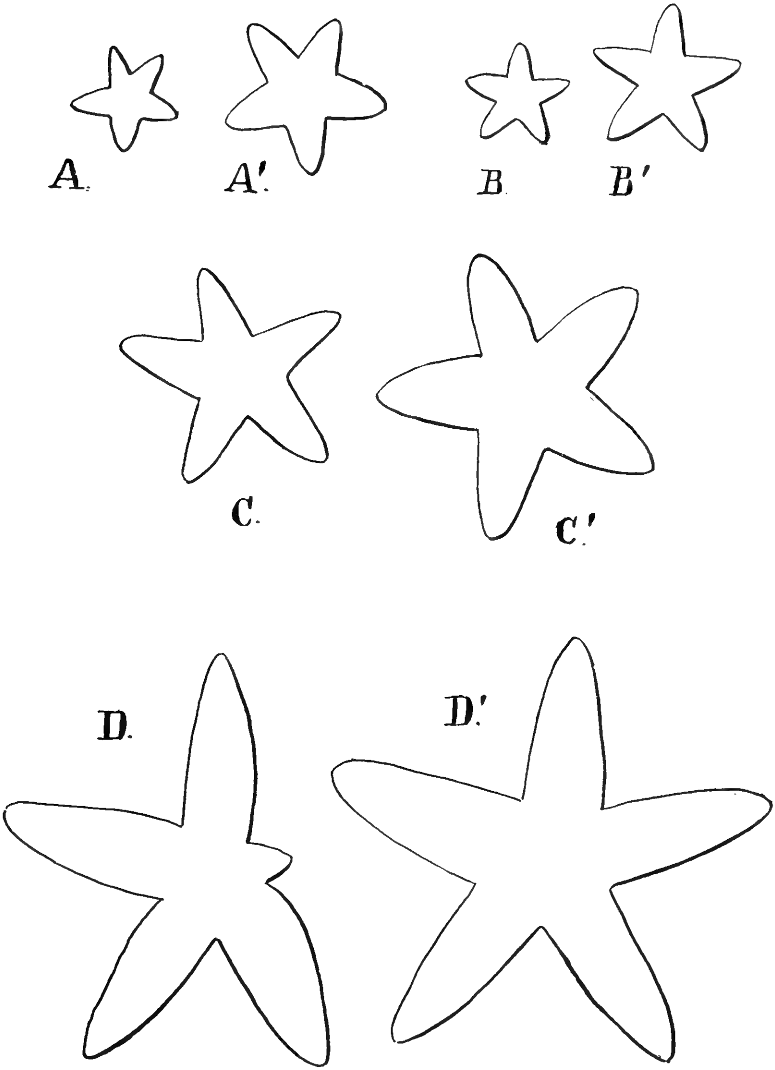
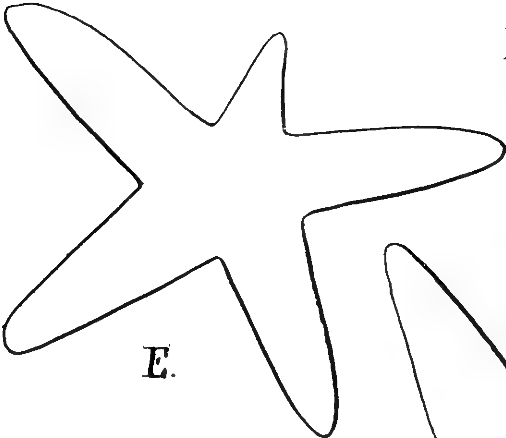


Fig 23. (contd)



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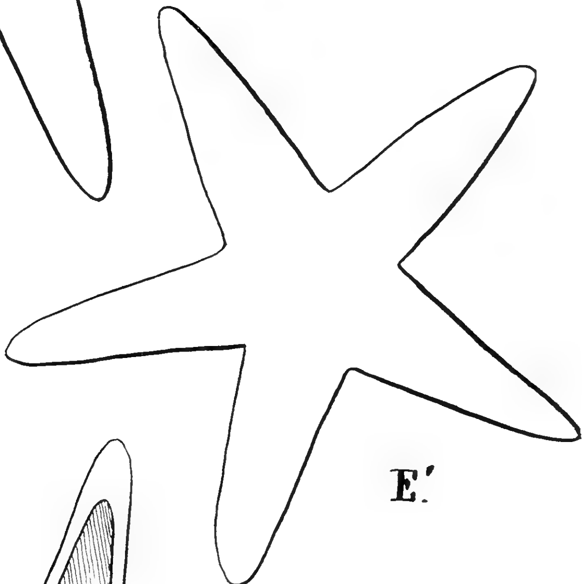

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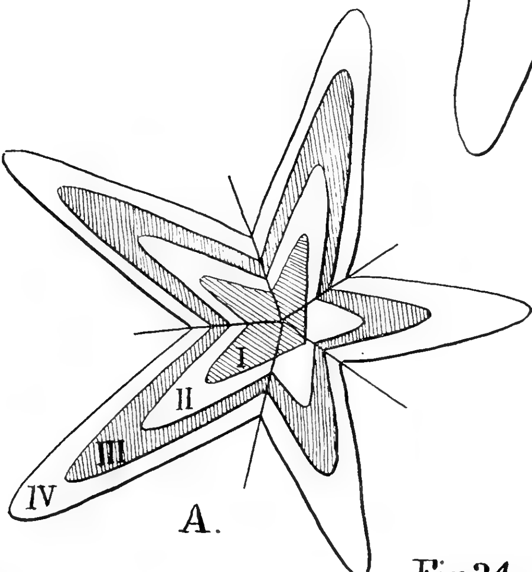


A.

B.

Fig 24.

Fig 25.

Fig 26.

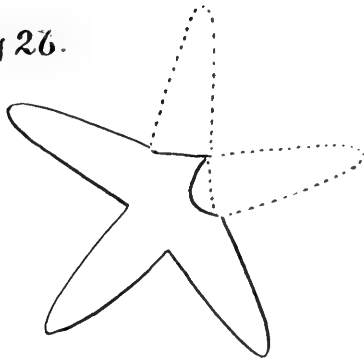


Fig 27.

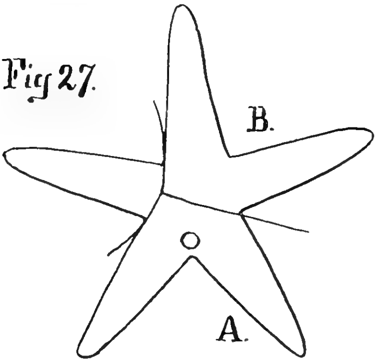
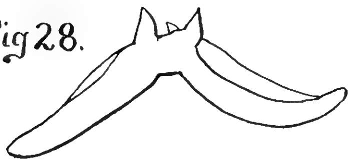


Fig 28.



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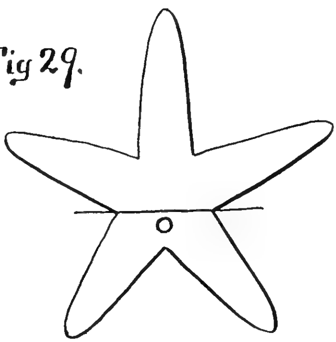

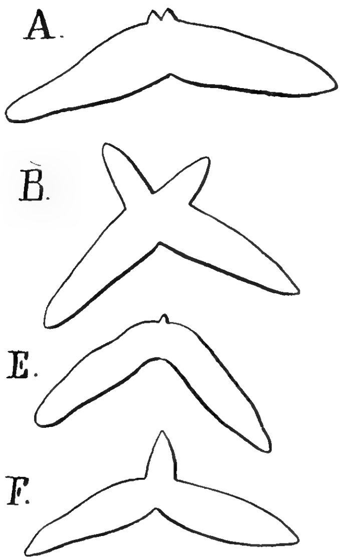

Fig 30.

IX. *A study of the life-habits of the clam.*

This investigation has been undertaken for the purpose of determining the reasons for the present depleted condition of the clam beds, and to test the feasibility and practicability of restocking the same through methods of artificial propagation. The investigation was entrusted to Prof. J. L. Kellogg, who has made a special study of the lamellibranchs (the natural group to which the oyster, clam, and scallop belong), and who is amply qualified to write authoritatively respecting the various problems of marine life.

SPECIAL REPORT

ON

THE LIFE-HISTORY OF THE COMMON CLAM,

MYA ARENARIA.

BY PROF. JAMES L. KELLOGG.

On several occasions in past summers I have noticed, in June and July, on the eel-grass and *Ulva* in the vicinity of Woods Hole, Massachusetts, some very small bivalves which were attached by a byssus. The outline of the shell was such as to suggest a similarity to the long necked, or soft clam, *Mya arenaria,* and yet the differences were considerable so far as form was concerned. The whole outline was rounded, and the umbones prominent and widely separated, while in the adult clam the shell is elongated from before backward, the inconspicuous umbones approaching each other closely near the median line. The character of the hinge might have determined the matter, but it was so small and fragile in the few specimens which I had picked up in the search for other material, that examination was difficult and uncertain. I had always had a suspicion, however, that a study of these forms would show them to be the young of our common clam.

Among the numerous notes and papers by the late Professor John A. Ryder, of the University of Pennsylvania, I find a short description of the young *Mya* attached by a byssus.* A few in-

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*American Naturalist for January, 1889, embryological notes.

dividuals were found in New Bedford harbor by Vinal N. Edwards, of the U. S. Fish Commission. These forms were attached to floating timbers, together with masses of ascidians (*molgula*). Professor Ryder, in his study of them, found in a few specimens, a single byssus thread arising from a byssus gland in the foot.

Being invited by Dr. H. C. Bumpus, of Brown University, who represented the Rhode Island State Fish Commission, to make some investigations on the life history of the clam during the summer of 1898, I proceeded to Woods Hole, Massachusetts, to consult with him in regard to the work. Soon after my arrival, I was informed by Dr. A. D. Mead, who had just returned from the Kickemuit River, in Rhode Island, that he had observed a small bivalve in great numbers in the seaweed in which were also to be found the small starfish which he was engaged in studying. On proceeding to the "River," I found the creatures which I had previously seen at Woods Hole in countless numbers attached by a byssus thread to the matted filaments of the marine alga *Entermorpha*, and rarely to *Ulva* and eel-grass. The *Enteromorpha* was attached to the long blades of the eel-grass, and to stones on the bottom, and was found only near the beach, which contained a great many clams. The small lamellibranchs I soon determined to be the young of *Mya*, and the following is an account of their development and habits from the period of their fixation by the byssus thread to the adult condition.

Not being able to reach the shore before the last of June, I was unable to obtain material for the study of the embryonic stages of the development.

SOME STRUCTURAL PECULIARITIES OF THE SMALL CLAM.

Many of the attached forms were extremely small. Several were obtained which were but $\frac{4}{16}$ of a millimeter in length, and these the unaided eye could with great difficulty distinguish from fine grains of sand. A glance at Figure 2, which represents an individual of this length, shows a creature with little resemblance to

the adult *Mya*. The outline is rounded, and the umbones are very prominent, and project out so as to be widely separated from each other. The foot, also, is of the ploughshare shaped variety, found in such clams as *Venus*, *Unio*, and many others, and, though not so represented in the figure, may be seen through the delicate semi-transparent shell to extend over the entire ventral surface of the visceral mass. In this it is very unlike the hatchet-like foot of the adult *Mya*, which is relatively small and projects forward from the anterior surface of the visceral mass. The siphons (8), however, are similar to those in the adult form, but are excessively delicate and filmy, occupying so little space when retracted that the shell does not gape posteriorly to accommodate them. They are protracted and retracted with the utmost facility and rapidity.

It was not difficult, however, to determine that these individuals were young long necked clams. When arranged in a series from smaller to larger forms, very slight differences between contiguous individuals, as regards the outline of the shell, lead from the rounded form with prominent umbones to the elongated shell of the adult, in which the umbones are inconspicuous. This comparison is illustrated in Figure 1. The outlines of the shells of a few individuals have been selected from a much greater series. They represent forms from $\frac{4}{10}$ of a millimeter to $7\frac{1}{2}$ millimeters (less than $\frac{5}{16}$ of an inch) in length. The largest shell differs from that in the adult in having the still conspicuous umbones placed anterior to the middle of the shell, but the general appearance is much the same, and the changes in outline from the one to the other are easily followed in intermediate sizes.

In drawing a great many outlines with a camera, two individuals of the same length very frequently presented differences in outline which were considerable. Everyone has probably noticed how great are these individual variations in the shells of the adult clams, even in those cases where the shells have not become distorted in growth by coming in contact with unyielding bodies, such as imbedded stones. The outlines selected and reproduced

in Figure I are, of course, respresentative, and show one or two curious facts which would appear in any similar series.

The first of these is that the small rounded shell, as already described, becomes relatively much elongated. Again, in the shell $\frac{4}{10}$ of a millimeter in length, the umbo appears near the middle of the shell, and then rapidly shifts its position anteriorly as the creature becomes older. In outlines 9 and 10 in the series (in individuals 6 and $7\frac{1}{2}$ millimeters in length respectively), the umbones are being gradually moved back toward the middle of the shell, and this is continued in older shells until, as in the adult, they have again assumed a position about equally distant from the anterior and posterior extremities. This shifting in the position of the umbones is of course due to the fact that the shell for a time grows more rapidly posteriorly, and at a later period the anterior part has a period of more rapid growth.

In shells not longer than 2 millimeters, it is not difficult to detect the usual tooth in the left valve (as well as the excavation in the right), which Gould and Binney describe in the adult as erect, "rounded at its summit, of about equal breadth and height; its inner face is smooth and rounded; its outer face is divided into two portions, the largest of which is spoonshaped, the other flat, and traversed across the middle by a grooved ridge, which projects beyond the margin of the tooth like a smaller tooth." This description may be easily applied to the small shell.

In the smallest forms examined there was a concrescence of the mantle folds similar to the condition in the adult. There can be no doubt, as appears from the enumeration of these peculiar anatomical conditions, but that the small form here described is *Mya arenaria*.

ATTACHMENT.

One of the most interesting features of the life-history of the long necked clam—interesting from an economic as well as from a scientific point of view, as I shall attempt to show—is the fact that it is attached by a byssus to foreign objects during a considerable

period of its early life. The smaller forms which I was able to find in the seaweed above the bottom were minute in size, some being but $\frac{4}{10}$ of a millimeter in length. In every individual there was to be found a well developed byssus, which afforded a rather firm hold to the filaments of the weed. All the clams in the weed of course maintained their position by the same means, and the largest of these which I found, when I made my first examination early in July, was 7 millimeters in length (a little more than $\frac{1}{4}$ of an inch). A search early in August revealed several somewhat larger than this, each attached by a byssus, and in the mud of the bottom also many were obtained, some of them from 10 to 13 millimeters in length, which still possessed a well developed byssal thread.

In the note by Professor Ryder, spoken of above, a statement in regard to the size of attached individuals is not quite clear. He says: "As they grew larger it was further supposed that they were held fast in their unusual position by the fibres and cement substances secreted by the mantles of their ascidian neighbors, and thus were suffered to attain a considerable size (from two to fifteen millimeters). * * * However, further investigation showed that in this I was in error, for after a careful search, a few individuals were found from which a single byssal thread was found to proceed." From this statement it does not appear positively that any individual fifteen millimeters long was seen to have a byssal thread attaching it to a floating body, though such possibly may have been the case.

Beginning work early in July, I was unable to find sexually mature adults either in Narragansett Bay or at Woods Hole, the breeding season evidently coming earlier in these localities, probably in May and June. That a few individuals still continue to discharge sexual cells late in July, however, we have evidence in the fact that even in August there appear on the seaweed a few very small forms which must be comparatively young.

We are led to the conclusion, then, that the free-swimming embryos attach themselves to foreign objects, such as the seaweed *Enteromorpha*, to eel-grass, *Ulva*, stones, and other bodies,

and that these attachments by the minute clam take place in the months of June, July, and August—the great majority of them in Narragansett and Buzzards Bays in the latter part of June and in early July. Having become fixed in this way by a byssal thread, the clams remain for some time, many of them attaining a length of at least 6 or 7 millimeters, and perhaps more.

FREEING FROM ATTACHMENT.

It may be well to notice, at this point, the fact that the attachment of the clams may be broken at any time, apparently at the will of the animal, by a casting off of the byssal thread. This is a very usual phenomenon among lamellibranchs with a byssus, and may be well observed in the black mussel, *Mytilus edulis*, where the byssus is very greatly developed. Here, as well as in the young clam, all the threads may be cast off from the gland in the foot, and new threads may be produced at will. Apparently young clams of all sizes in the weed very often perform this function. When they have in this way made themselves free in a glass dish, they at once begin to move about by means of the well developed foot. Slowly crawling about for a time, they finally conclude to reattach themselves, and even after this has been accomplished, they often crawl about in various directions to the length of their tether. In this process of freeing and reattachment, however, it often happens that the little clams fall from the supporting weed altogether, and reach the bottom. In order to determine, if possible, how frequently this happened, I kept a large mat of *Enteromorpha*, covered with clams, floating in running sea water. Under the mass was spread some fine cloth. In the course of a week, great numbers—perhaps a fourth of all those attached—were found to have fallen from their support on to the cloth, and these were of all sizes. Here they attach themselves, wander about, and again attach, until, apparently tired of the effort to find congenial surroundings, they remain inert, most of them without byssal threads, for long periods of time.

MIGRATION TO THE MUD.

As one would naturally suppose, this period is a critical one for the clam, as much so probably as any in its history, though the creature has to contend with other great dangers also, which threaten its existence both before and after it enters the mud. The eel-grass on which the *Enteromorpha* filaments grow most abundantly in the localities examined is to be found in shallow water, near the clam beds. In falling from their support, most of the clams would probably find a resting place on the bottom, below the lowest low tide mark. That this actually happens may be easily demonstrated by taking a little of the mud in these localities and washing it through a fine sieve. When this is done the small clams are easily found. It is probably not possible for many of these creatures to reach maturity in this position. I have dug clams below what I should judge was the lowest low tide mark in the salt pond at Wakefield, R. I. On a recent visit to Essex, Mass., I was told by a few of the clam diggers that there were long-necked clams in the bottom of the Essex River, which were always covered by many feet of water. One or two of the diggers believed these clams to be unlike the common long neck in some few details of structure. I was unable to obtain any of the forms for examination, and consequently do not know what this information may be worth. Though it is possible that *Mya* may, in some instances, be found in bottoms which are never exposed, it seems to me altogether probable that such areas are not numerous. Clam diggers very generally seem to know nothing of their existence.

I should conclude, then, that of the great numbers of small clams which fall from the seaweed to the bottom below low tide mark, few are able to reach a favorable position higher up on the beach, and the great majority are destroyed. I have seldom found, in such localities, individuals more than 6 or 7 millimeters in length. While the majority may thus perish, we may well believe that a few, on falling at certain times, are borne by tidal currents above

the low tide mark. They are to be found here burrowed into the sand, or attached to the sides of stones, down close to the line where the stone touches the mud. This occurs most often on stones covered by rockweed (*Fucus*), and probably for the reason that here the little clams find better protection from their most destructive enemies, the young starfish. It is possible that some of these small clams between the tide marks originally attached themselves in this position, never having been fastened to objects in the water below low tide mark.

This wholesale destruction of individuals below low water mark is but another example of the tremendous struggle for life to which so many species of organisms are subjected in nature. Of the millions of swimming larvæ that probably arise from one female during a breeding season, few become attached to suitable objects, the water currents carrying most of them away. Those which succeed in fastening themselves are killed in vast numbers by very small starfish; and even after attaining a position in the sand and mud of a favorable locality, the shifting of the sand, the crowding of individuals, the decay of organic material in the water, or the isolation of salt water in shallow arms of the sea, leads to the destruction of many. Considering these phases of the life-history of the soft clam which I have thus far described, it seems that artificial methods might be developed which should remove some of the dangers to be found in nature, and hence lead to a greater increase in the number of adults.

BURROWING INTO THE MUD.

The migration from the point of attachment having been accomplished, we are next concerned with the habit of burrowing into the mud. In the adult clam the foot is reduced to a laterally compressed, finlike projection from the anterior side of the visceral mass, not extending down on to its ventral surface. It is with great difficulty that the mature clam buries itself in the sand after having been dug from its burrow. Clams from one to two

inches in length will cover themselves gradually in the course of from half to three-quarters of an hour, but they reach the usual depth of several inches only after a much longer period. Very large clams out of their burrows seem to be entirely helpless. In the young, the foot is relatively very much larger than in the adult, and extends from the anterior side of the visceral mass, just under the mouth, far back on its ventral side. This condition of the foot is almost exactly like that to be found in such a clam as the quahaug (*Venus mercenaria*) in its mature state. *Mya* has probably descended from an ancestral form which possessed this plowshare-shaped foot, its organ of locomotion being reduced to its present form because it became less and less an organ of locomotion, and was used simply for digging downward into the sand. We have a confirmation of this view in the structural peculiarities of the foot in the very small *Mya*, as described above.

In the young *Mya* the foot is capable of great extension, and is used not only in crawling over objects, but also in digging into sand and mud. It is extremely interesting to notice that individuals but $1\frac{1}{2}$ millimeters long (I have not happened to observe it in smaller forms), when placed upon sand, at once attempt to cover themselves by thrusting and worming the sharp anterior part of the foot into it. Unless the sand be extremely fine, clams of this size are not able to thrust aside the grains sufficiently to obtain a lodgment. Those measuring 2 or 3 millimeters in length are sometimes able to cover themselves partially or wholly; while an individual 6 millimeters long can usually work its way beneath the surface of any clam bed, and thus rest in comparative security. All clams which I have observed, under 6 or 8 millimeters in length, work their way downward only far enough to cover the shell. None of them seem to be overly energetic, and many times, after working long enough to raise the posterior end of the shell into a vertical position, they give up the attempt to bury themselves, and remain in that attitude until toppled over by the water currents. After having become completely covered they exhibit a great deal of restlessness, and apparently often push out to the

surface again, as if dissatisfied with the surroundings, and, after wandering about for a short distance, once more go down. This process I have known to be repeated, in an individual 6 millimeters in length, half a dozen times in the course of three days. They seem to wander short distances—one or two inches only—between the periods of descent, but I have noticed it in few cases, and perhaps the wanderings on the surface of the bottom may at times be more extensive. How large the clam is before it finally digs into the bottom to remain permanently, I am not able to say. I have frequently found lying on the surface empty shells at least 2 centimeters long which had been perforated by the oyster drill (*Urosalpinx*), which could only have made its attack when the living clam was out of its burrow. Clams of this length, then, apparently have periods of wandering, and it would be interesting to determine, if it were possible, whether or not they would be able to move up between the tide marks from some position below low tide. When dug out of the bed, clams measuring 2 or 3 centimeters in length are generally found to have gone down 12 or 15 centimeters (5 or 6 inches) from the surface, the extremely delicate and filmy siphons of the small individual becoming relatively larger and more muscular. There undoubtedly comes a period—probably not far from this time—when the clam ceases to come to the surface, and, except for some accident, remains forever buried, reaching up to the water only by means of the siphon tubes. Evidence of this we have in the fact that clams are frequently to be found between rocks in such a position that it would be impossible for them to move, having reached such a location when smaller. Then, too, shells, especially the larger ones, are frequently distorted and rendered asymmetrical by coming in contact, in growth, with an unyielding object, such as a stone. The shape in such cases conforms to the space in which movement is possible. This same distortion of the shell may be noticed in other burrowing lamellibranchs, like *Petricola pholadiformis*. In the case of this latter form, and also in *Pholas truncata*, which are to be found buried along the edges of salt marshes, the burrow is seen to be

surrounded by so dense a feltwork of roots from the marsh vegetation that it would seem entirely impossible that the adult animal could remove itself. It is a mystery how the young could ever force its way into such material.

FIXATION IN THE BURROW.

A peculiar habit, the utility of which is very evident, is the spinning of the byssus by the small clam as soon as it has succeeded in covering itself in the sand. As has just been stated, the small individuals bury themselves, and again appear upon the surface, and this is repeated several times. But whenever the creature goes into the sand, it apparently at once proceeds to pour out the secretion which forms the byssus thread, and attaches itself more or less firmly by this means. Figure 3 represents a clam with a shell $2\frac{3}{10}$ millimeters long which has been removed from its burrow. The single byssus thread (b) is seen to branch, the ends of the branches being attached to three sand grains (s. g.). Actually the number of sand grains and pebbles to which attachment is made is usually greater than represented. The extremity of the thread which is fastened to the foreign body is considerably widened, as shown in the figure. The character of the thread is the same, whether the creature is attached to several sand grains, or to a single filament of *Enteromorpha* or to other bodies. Figure 2 represents a very small individual, $\frac{4}{10}$ of a millimeter in length (drawn on a larger scale than Figure 3), which was attached by several branches of the byssus to one short seaweed filament.

In coming out of the burrow and moving to a new locality, the byssus is cast off at the gland in the foot and left behind, and a new one is constructed at the next descent. This is accomplished in the space of a few minutes. Clams, from the smallest which are able to cover themselves in the sand, to those at least 13 millimeters in length, exhibit this peculiar habit of forming a byssus in the burrow. How much longer the byssal organ remains in functional activity, and when it begins to atrophy, I have not determined.

The utility of this habit is well illustrated in a circumstance which recently came under my observation at the house-boat laboratory, in the Kickemuit Narrows, belonging to the Rhode Island Fish Commission. I had suspended in the water a box filled with sand which I had taken from a neighboring clam bed. In the sand I had sunken some glass dishes, about three inches in depth, and had filled these also with sand. Here I had allowed a number of small clams to burrow. On the 5th of August, the region was visited by a terrific wind storm, and everything connected with the house-boat was pitched about furiously for more than an hour. Upon examining the glass dishes afterward, I found that all the finer sand had been washed out of them, and but a few small pebbles remained. On these, however, several clams remained firmly attached, and this had prevented their being washed away. Where the waves were breaking on the beach, the same thing was probably happening. Small clams near the surface in their shallow burrows were probably washed out in great numbers. Many of them were then thrown up perhaps, and left to perish. I have been informed by clam diggers that during violent storms, when the tide is high, vast numbers of small clams are sometimes thrown up on the beach, and left high and dry to perish by the retreating tide. But while, under such conditions, many meet destruction, the possession of a byssus which is attached to pebbles and sand grains many times heavier than the clam itself must be of immense advantage in tending to keep the animal from floating off from the bottom.

THE BYSSUS THREAD.

Reference has been made to the relatively large, plowshare shaped foot which extends backward over the ventral side of the visceral mass. The byssus organ, in which the secretion for the thread is produced, is located in the usual position on the ventral side of the foot, and far toward its posterior extremity. Its position is indicated in Figures 2 and 3, in which, however, the foot is represented as being projected forward to a considerable

extent, carrying the byssus organ outside the shell. The byssus itself appears to be made of a single delicate transparent thread (b) sometimes bearing a number of side branches, the end of each branch forming a point of attachment. I have not had the time at my disposal to determine the manner in which attachment is actually accomplished, but it does not seem probable that it is effected exactly as in *Mytilus* (mussel) and the young *Pecten* (scollop), in which forms a groove on the ventral side of the foot leads from the opening of the byssus organ out nearly to the tip. This groove is converted into a closed tube, and the fluid secretion of the gland is poured out into it. At the tip of the foot it is allowed to come in contact with the body to which attachment is to be made, and adheres tightly. The groove of the foot is now slowly opened, and the secretion, upon coming in contact with the water, is converted into a tough fibre. *Mytilus* forms a number of threads in this way, which extend out in various directions, and all unite near the opening of the byssus gland.

In the clam, an attachment having been made at a few points, the thread may be greatly elongated by pouring the secretion out directly into the water where it at once hardens, much as the secretion from the spinning gland of a spider hardens, after its extension, by coming in contact with the air. By fastening a byssus thread from a clam 6 millimeters (nearly $\frac{1}{4}$ of an inch) in length to the point of a needle, I have been able, by exerting a gentle pull on the thread, to draw it out to a length of 5 centimeters (about 2 inches) in the space of about fifteen minutes. The secretion was poured out at intervals, but not at any time with much rapidity. The thread thus obtained appeared to be single, was very elastic, and was possessed of some degree of toughness.

POINTS BEARING ON THE DEVELOPMENT OF METHODS OF CLAM CULTURE.

The falling off in the supply of clams in Rhode Island has for some time been regarded with serious concern, and it is still

rapidly diminishing. Clam diggers everywhere on Narragansett Bay whom I have met during the present summer (1898) have given the most discouraging reports. In some localities, where clams were abundant four or five year ago, almost none can now be attained. The culture of oysters as carried on in Narragansett Bay, Long Island Sound, and elsewhere on the New England coast, has been attended by many great and serious difficulties, and yet it has become, in the hands of enterprising men, a very profitable business. In localities where it has been impossible to obtain a set of "spat," where the beaches between tide marks may not be used, where an annual rental of $10.00 an acre must be paid, where the deadly starfish abounds, and where oysters are purchased abroad and shipped great distances simply to be spread upon the bottom and allowed to grow to a marketable size, the business pays and is thriving. One or two abortive attempts have been made to develop methods of clam culture in this country, but for one reason or another—principally because of a lack of protection by law from the depredations of clam diggers—they have been discontinued. From the account of the life-history of the long necked clam given above, it would appear that it may be possible to develop culture methods which should be productive of much greater results than those obtained by oyster culture. Two or three points, brought out in the above account, as well as some facts not yet mentioned, may well be noticed as bearing on the solution of this economic problem.

(a) *The habit of attachment.*

Probably in many localities it would be possible, as it is in the Kickemuit "River," to obtain great numbers of young clams in the early summer, by simply gathering the floating seaweed to which they are attached, and transporting them to localities where the conditions should be most favorable for their further development.

Though I have no facts bearing on this point, it may be possible to bring about an artificial fertilization of the ova of the clam in

such a way that the swimming larvæ might be induced to attach to some suitable object, which should be convenient to handle, when it is suspended in the water containing the embryos. This has been accomplished with some degree of success in the oyster, where artificial fertilization may be brought about with very great ease. There are some lamellibranchs, however, in which it seems to be absolutely impossible to induce this union of the sexual cells, and this may be the case with the clam. Even if it were so, sexually mature individuals might be placed in enclosed localities, where large numbers of the young could be collected.

(b) *Tenacity of life.*

While the adult *Mya* dies easily in aquaria, if not occasionally allowed to lie exposed, or if the water becomes foul, the small clams are very tenacious of life. Early in July, 1898, a bucket full of *Enteromorpha*, covered with clams, was taken from the water at the Kickemuit Narrows at eleven o'clock in the forenoon of a hot day. This was carried to Woods Hole, Massachusetts, arriving at four in the afternoon, the water in the bucket having become very warm. These clams were transferred directly to the much colder sea water in the hatching house of the U. S. Fish Commission station. None of them seemed to be in the least injured by their rough treatment, and they lived in very slowly running water for over a month, when they were removed. In this case, no care having been taken to make the conditions favorable, they did not seem to thrive, and certain individuals, measured from time to time, showed little, or in some cases, no growth. However, some of these individuals, after remaining a month in the hatching house, were placed in small glass dishes which were allowed to stand until the water had nearly evaporated, and a zooglea mass had formed on top of it, and they remained alive under these conditions for many days. These facts seem to indicate that the small clams are very hardy, and, if desirable in culture work, could easily be transported without injury.

(c) *Effect of waters of differing degrees of salinity.*

In the transfer of clams just mentioned, it may be noticed that the salinity of the water in the two localities is somewhat different. In the Kickemuit the average salinity is about 1.019; at Woods Hole, about 1.024. As is the case with oysters, clams will live in water which is brackish. At the salt pond near Wakefield, R. I., for instance, the salinity I am informed by Dr. G. W. Field is from 1.0049 to 1.0058 on the surface, and quite a number of clams are to be found along its shores; the density at the bottom may be much greater than at the surface, however.

(d) *Enemies.*

One important fact which must be considered in developing any method of clam culture is that the clam in its attached condition, and when exposed on the surface of a bed, is destroyed in vast numbers in many localities by one or two natural enemies. The worst of these is that curse of the oyster culturist in northern waters—the starfish. Many extremely interesting and important observations in regard to this creature's habits of destroying clams and other forms have been made during the past summer by Dr. A. D. Mead. These observations show that the starfish, even when minute in size, is terribly destructive to the young clams.

Another enemy of the young clam is the oyster drill (*Urosalpinx*). I have taken many clam shells from the surface sand of the bottoms, which exhibited the clam perforation filed by this creature. Shells so pierced were from 3 millimeters to 2 centimeters or more in length. As I have never found drilled shells in any great numbers in one locality, it would appear that the clam is not seriously menaced by this foe. The adult clam, deep below the surface, is probably not disturbed by other enemies than man.

SUMMARY.

To recapitulate the principal points established in the above description of the life-history of the clam, beginning after the swimming larval condition: The breeding season in Narragansett

and Buzzards Bay probably extends through May and June into July. Beginning my observations late in June, I have not been able to determine its limits with any certainty. After the free swimming larval period, the young clams attach themselves by means of a byssus, which is produced from a byssus gland in the foot. Attachment is made to various bodies in the water, but chiefly to the filaments of *Enteromorpha*, a green seaweed growing near the shores. Clams may be found so attached from the latter part of June to the first of August. They are to be found in certain localities in immense numbers. The attached individuals measured varied in length from $\frac{4}{10}$ millimeter to 7 millimeters. The shape of the smaller individuals differs greatly from that of the adult in being much more rounded, with umbones widely separated laterally. As they become older, they gradually assume the outline which characterizes the adult, but in so doing the umbones come to be situated relatively far forward and then again move back toward the middle of the shell on the dorsal side. This shifting in the relatative position of the umbo is due to a more rapid growth of the posterior, and subsequently of the anterior ends of the shell.

In the smallest forms examined, the mantle folds were in concrescence ventrally. The foot is relatively greatly developed, extending over the entire ventral side of the visceral mass. The siphons have the general characters of those in the adult, but they are filmy, and may be retracted within the shell with very great quickness.

Clams of all sizes are apparently freeing themselves from their attachment on the weed. The byssus is cast off, and the creature climbs about from one filament to another by means of the foot, sometimes reattaching, sometimes falling free from the weed to the bottom. In the sand, unless it be excessively fine, individuals less than 2 millimeters in length are rarely able to cover themselves, though they always make the attempt. Those 5 or 6 millimeters long are apparently able to burrow beneath the surface of any clam shore.

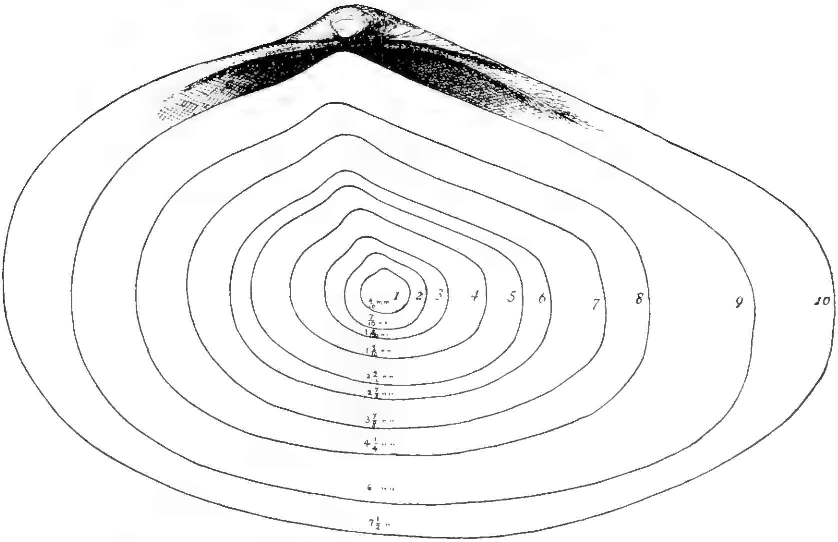


Fig 1

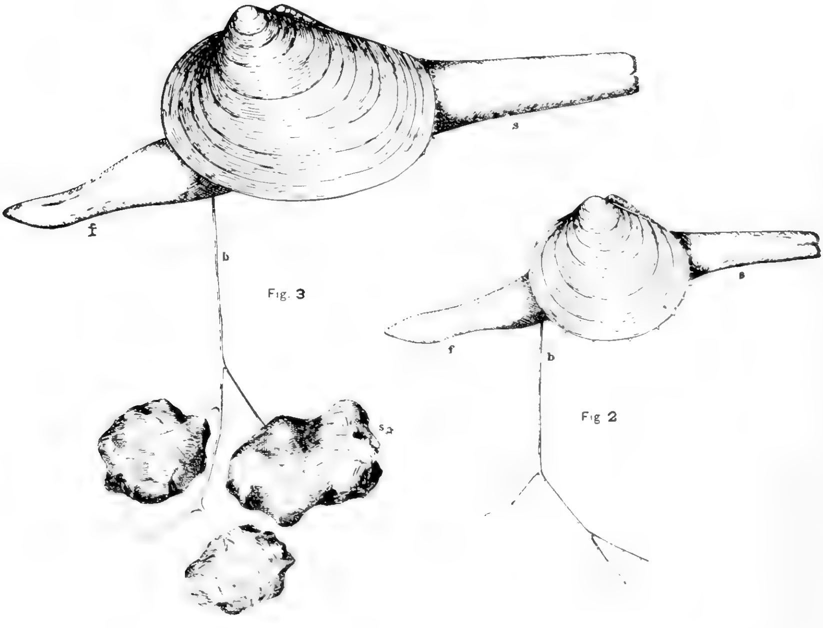


Fig. 3

Fig 2

Having attained a lodgment in the sand, all clams observed at once proceed to form a byssus thread, which is attached to sand grains and pebbles. This tends to secure the creature, so that, even if water currents or the action of the waves should dislodge it from its burrow, it would not be carried so far from its original position as would otherwise occur.

Of their own accord these clams frequently leave the first burrow, wander about, and form another, some individuals repeating the process many times. A time finally comes when they dig into the sand to remain permanently.

DESCRIPTION OF FIGURES.

FIGURE 1. *Mya arenaria.* Ten camera outlines of shells varying in length from $\frac{4}{10}$ of a millimeter to $7\frac{1}{2}$ millimeters. They are intended to illustrate the change from a rounded outline in the smaller individuals to the elongated condition of older forms. In this there is at first a more rapid posterior, and subsequently a more rapid anterior, growth of the shell, which causes the relative position of the umbo to shift forward, and then back to a position midway between the two extremities of the shell.

FIGURE 2. *Mya arenaria.* An individual with shell $\frac{4}{10}$ of a millimeter in length. Removed from attachment to seaweed (*Enteromorpha*) and showing the single, branched byssus thread (b) arising from a byssus gland at the base of the foot (f). The filmy siphons (s) are shown protracted.

FIGURE 3. *Mya arenaria.* Form $2\frac{3}{10}$ millimeters long (drawn on smaller scale than Figure 2), removed from burrow in sand, and showing attachment of byssus (b) to numerous sand grains (s. g.).

X. *The preparation of a relief map of Narragansett Bay.*

It is self-evident that a thorough knowledge of the habits and distribution of fish in the waters of the Bay requires a knowledge of the territory itself, and particularly of the configuration of the floor of the Bay and of the sedimentary deposits. The Commission, therefore, has prepared a large relief map, which gives an excellent idea of the distribution of fresh, brackish, and sea water, and enables one to determine at a glance the location of the fish traps, their relation to the channels, and the various shallow water tracts already available or adapted to successful clam and oyster culture.

XI. *An examination of the feasibility and practicability of artificial lobster culture.*

That the lobster industry of Rhode Island is rapidly waning needs no argument. The incessant unrestricted capture of the adults and young, the annual destruction of many millions of eggs by indifferent fishermen, and the inroads made upon the native supply by those not inhabitants of the State, have so reduced the annual catch that the industry is no longer profitable, and the lobsters themselves are sold at prices that make them prohibitive to many as a regular article of food.

The artificial hatching of the lobsters' eggs is an extremely simple matter, and has been carried on for many years in Norway, New Foundland, Gloucester, and Woods Hole; but the young (Plate A, Fig. 1) when liberated are in no condition to care for themselves. They swim or float about in the ocean, their bright colors rendering them attractive to predatory fishes. Currents carry them far from their native grounds, and it is probably safe to say that scarcely one in a thousand finally reaches a matured condition. It is evident then that the mere planting of lobster fry, can have little, if any, effect towards rehabilitating the lobster industry.

The helpless lobster fry swim about in the water for a period of

about four weeks, during which they pass through the stages represented in Figs. 1, 2, 3, before settling to the bottom to assume the shape and retiring habits of the adult (Plate B, Fig. 4). If it were possible to carry the young lobster through this free-swimming period of their youth, there is every reason to believe that the young so reared would, on liberation, seek hiding places in the crevices of rocks, under shells, etc., and the period of greatest mortality would thus be overcome.

Efforts repeatedly have been made to brood the young, but the animals are so delicate, and at the same time so voracious, that it is extremely difficult to keep them alive in any of the more ordinary forms of hatching apparatus. One of the Commissioners, during the past spring, prepared several large "fish-cars" (about sixteen feet in length, six feet in width, and five feet in height), with fine wire mesh, the holes of which were sufficiently large to enable many small animals to enter as food, but so small that the young lobsters could not escape. The bottoms of some of these cars were covered with gravel and pieces of growing seaweed, and everything was done that could be done to make a natural environment.

The experiment, so far as the young lobsters were concerned, was a failure. The young of rapidly growing predatory animals worked themselves into the car and preyed upon the helpless larvæ. The sea water, laden with dirt and sediment, on reaching the more quiet water of the interior of the car, simply precipitated its refuse and left a quantity of decaying organic matter to poison the water.

The next experiment consisted in the placing of a large cheese-cloth cage inside of one of the fish-cars. The mesh of the car thus protected the finer mesh of the cheese-cloth frame, but the young lobsters did not flourish. There was not sufficient motion to the water to keep them floating; their feet became entangled in the fibres of the cloth, and they preyed sadly upon each other.

The breeding season of the lobster is not sufficiently extended to enable one to experiment along a large number of lines, but

before the close of the season the results obtained were more encouraging. Several lobsters were actually raised to that stage when the characters of the adult are assumed—the fourth molt, Figure 4. These young lobsters were raised in a car of somewhat novel design, but so arranged that the water after flowing into the car has a considerable amount of motion. The fry were fed upon shreded codfish, which contains a sufficient amount of air to cause it to descend only slowly through the water, and it thus becomes an attractive object to the young animals, which quickly follow any moving object. At times minute pieces of fresh fish were greedily devoured, and the writer has repeatedly seen the young animals follow the scent, which has been left in the sea water by a piece of slowly descending fish, until several pounced upon the object when it finally reached the bottom of the aquarium.

The results of the season's experiments are such as to warrant a continuation of the work. We know perfectly well that many others have failed in doing what we attempt, but until we are thoroughly convinced that the young lobster cannot be "brooded," we propose to continue our work.

XII. *The extension of the commercial fisheries of the State through the discovery of new localities for food fish.*

The extension of the commercial fisheries of the State through the discovery of new localities for food fish at first impression would appear absurd in a locality so well known as are the waters of Rhode Island, but only a short distance to the south (a distance that can readily be covered by an ordinary sailing vessel in a single night) are the warm waters of the Gulf Stream, and a member of the State Commission has conducted several expeditions, in the United States Fish Commission Schooner "Grampus," to the edge of the continental plateau, for the purpose of determining the presence of a valuable food fish discovered there some years ago, but since supposed to have become extinct. These

Plate A.

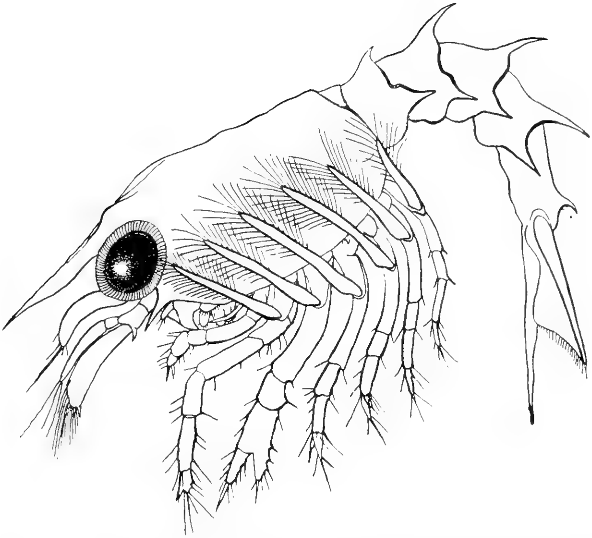


Fig. 1. Larval lobster at time of hatching—enlarged fifteen times.

(*From F. H. Herrick*).

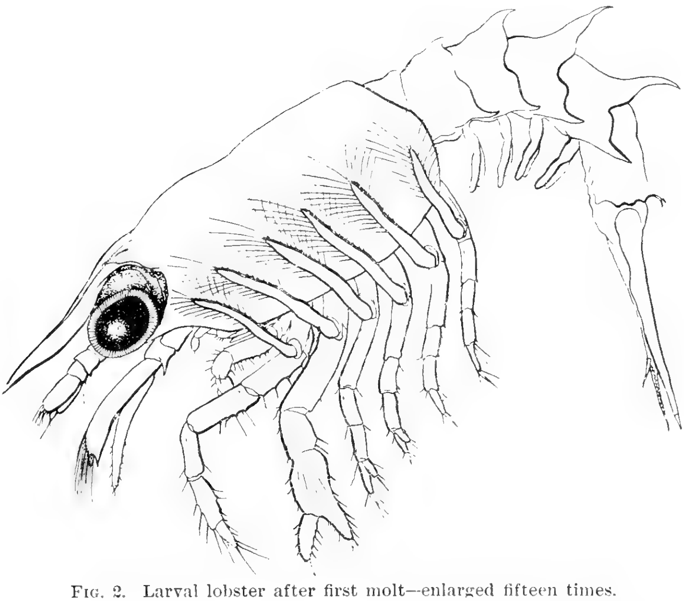


Fig. 2. Larval lobster after first molt—enlarged fifteen times.

(*From F. H. Herrick*).

Plate B.

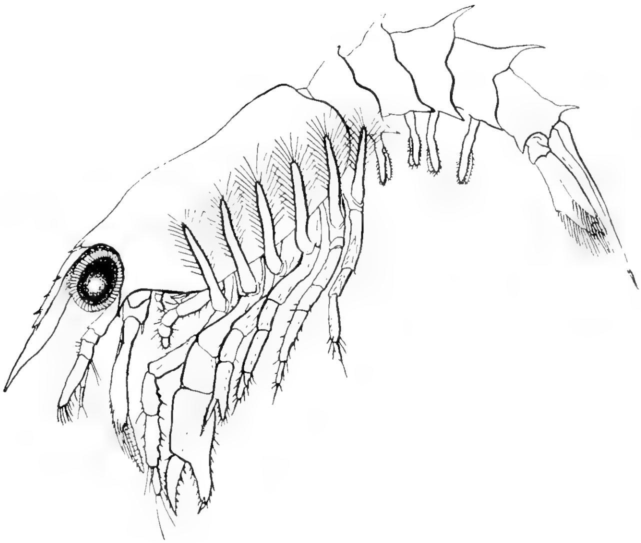


Fig. 3. Larval lobster after second molt—enlarged eleven times.

(*From F. H. Herrick*).

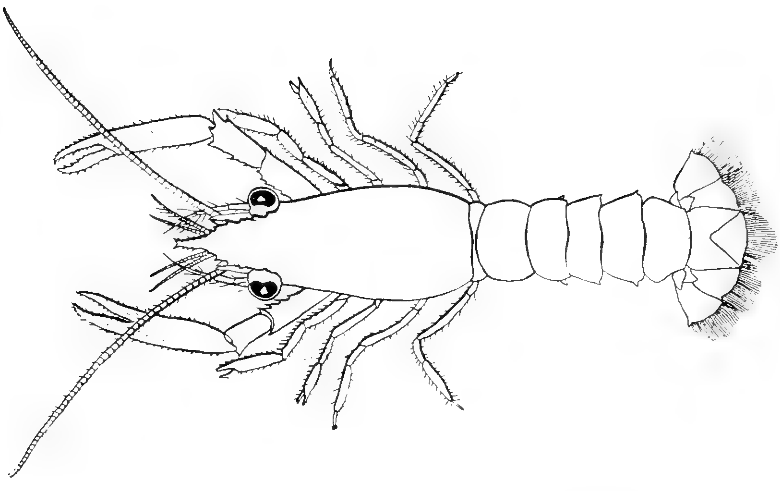


Fig. 4. Young lobster after third molt—enlarged five times.

(*From F. H. Herrick*).

expeditions have resulted in the capture of large numbers of tile-fish, and the definite location of a fishing ground which may develop an industry of great importance. The exact location of this tile-fish ground is indicated on an accompanying chart.

As is well known, a cold Arctic current flows westward between our coast and the Gulf Stream, and it is in this colder and shallow water that the cod and haddock fisheries are largely carried on. The Gulf Stream as it approaches the north is deflected from our shores by this Arctic current, and its deeper waters are also deflected by the steep bank of the continental plateau. The bottom in this neighborhood drops off very rapidly to a great depth, where the water becomes excessively cold. There is thus left on the upper edge of this bank a band of water, brought by the Gulf Stream from the south, which is both very much warmer than the shallow water lying immediately on the north and the deeper water lying on the south. It is in this narrow band of the sea bottom that the tile-fish, a tropical animal, finds an abundance of food, and it occurs in great numbers.

The following is a brief history of a fish which promises to become of great economic importance to our State.

ON THE REAPPEARANCE OF THE TILE-FISH.*

(*Lopholatilus chamæleonticeps.*)

During March and April, 1882, the presence on the surface of the ocean of large numbers of dead tile-fish gave rise to considerable discussion in scientific journals, and frequent allusions have since been made in text-books, and elsewhere, to this phenomenon as illustrating the elimination of a species in recent times by purely natural agents. The reappearance of the fish in abundance in its original locality is, therefore, of considerable biological interest.

* [*Reprinted from* SCIENCE, *N. S., Vol. VIII, No. 200, Pages 576–578, October 28, 1898.*]

The history of the discovery, the "extinction" and reappearance is as follows:

In May, 1879, Captain Kirby, of Gloucester, caught a great number of tile-fish off the southern coast of Nantucket, in water about 150 fathoms in depth. Specimens were sent to Washington, and the species was described by Goode and Bean in the "Proceedings of the U. S. National Museum" for that year. In July, Captain Dempsey, also of Gloucester, found several specimens in practically the same locality.

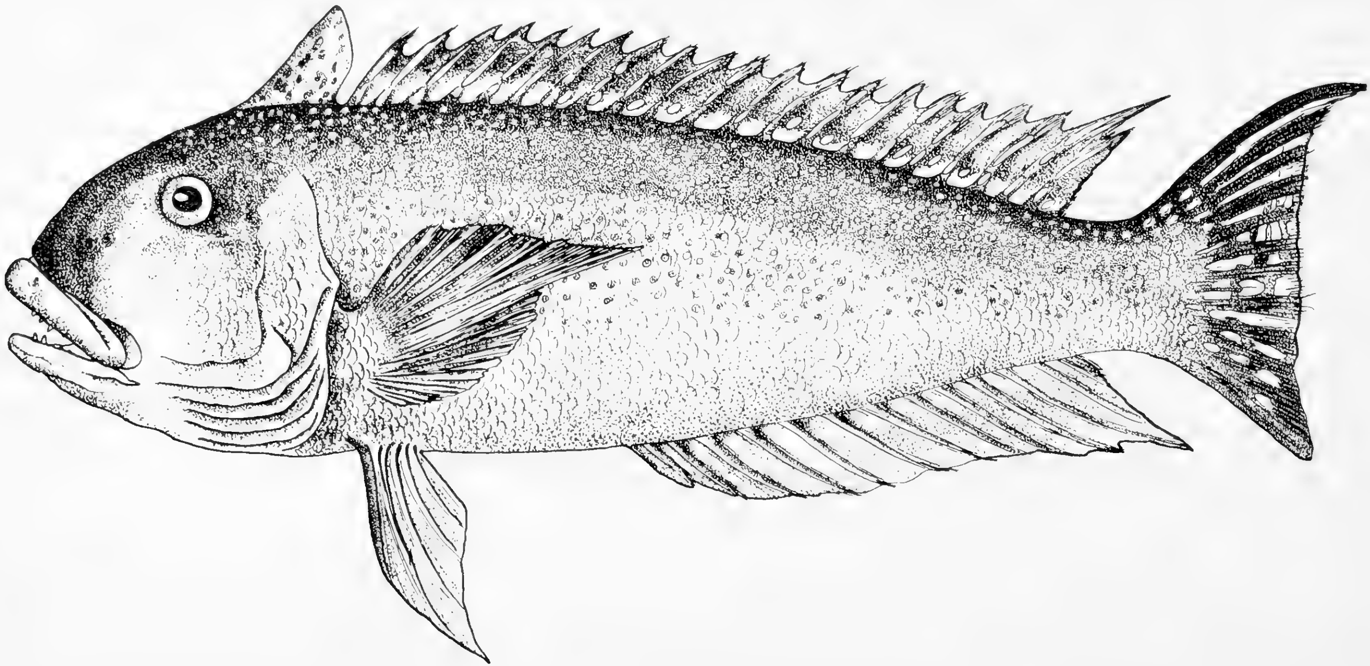
In 1880 Professor Baird sent the "Mary Potter" to search for the fish, but the expedition, on account of uncommonly severe weather, was not successful. The "Fish Hawk," however, while exploring along the continental plateau, caught several specimens.

In 1881 the "Fish Hawk," continuing deep-sea work along the southern shore of New England, caught a large number, and Professor Baird felt confident that he was about to establish a new industry.

In March and April, 1882, vessels entering New York and other Atlantic ports reported that they had passed through countless numbers of dead fish while crossing the northern edge of the Gulf Stream. Investigation proved that these were tile-fish, and that they appeared on the surface of the water for an extent of 170 miles in length and 25 miles in width. A conservative estimate, made by Captain J. W. Collins, placed their number at upwards of 1,438,720,000. Allowing ten pounds to each fish, there would be 288 pounds of fish for every man, woman, and child then in the United States. In September, Professor Baird chartered the "Josie Reeves" and sent her to the tile-fish grounds, that he might ascertain to what extent the species had been depleted; but the vessel returned without having found a single individual.

In 1883 the "Albatross" made further search, but without success.

In 1884 the "Albatross" made a more careful investigation, but again without success.



Tile-fish. (*Lopholatilus chamæleonticeps*).

In 1885 the same vessel searched from Newfoundland to the Gulf of Mexico without discovering the least trace of the tile-fish, though *Munida*, a species of crustacean upon which the fish was known to have fed, was found in abundance.

In 1886, 1887, 1888, 1889, 1890, and 1891 nothing new was learned.

In 1892, at the suggestion of Professor Wm. Libby, Commissioner McDonald fitted out the "Grampus," and on August 5th trawls were set on the old tile-fish ground. No fish were taken. On the 6th the trawls were set again, and one specimen, weighing seven pounds, was brought to the surface. This was the first specimen that had been seen since the mortality of 1882, ten years before. The "Grampus" continued her work, and in about two weeks caught a second specimen, which weighed thirteen pounds. On September 17th one specimen was caught, and on September 18th three specimens were taken. No more were caught until October 8th, when two were found off the Delaware coast. Thus, in 1892, a search of two months yielded only eight specimens.

In 1893 the "Grampus" resumed the search throughout the months of July, August, and September and caught scattering specimens.

During 1884, 1895, and 1896 no additional information relative to the fish was secured.

On February 8, 1897, the Schooner "Mabel Kenniston," of Gloucester, was overtaken by a gale on George's Bank and blown 120 miles toward the southwest. After the gale, trawls were set in sixty-five fathoms of water, and thirty tile-fish were caught. These weighed from six to fifteen pounds each. They were landed at Gloucester on February 16th.

On August 12th, of the present year, the "Grampus" left Woods Holl with a small party of scientific men, and sailed to a point about seventy miles south of No Man's Land. At the first set of the trawl, eight beautiful tile-fish were taken. The boat, insufficiently equipped with lines and bait, at once returned to the "station." New trawls were purchased and on August 30th, ice

and bait having been taken on at Newport, she again sailed south. The following morning, when the boat was only sixty miles from Block Island, the trawls were set. The first haul yielded seven fish; the second, forty-seven, and the third, nineteen. On the following day seventy-eight fish were taken, many of them of large size, and the vessel, now bearing 1,000 pounds, headed for Montauk Point, where the fish were given to the soldiers at Camp Wikoff.

When one considers that the trawls were short, provided with only a few hooks and tended by only one dory, it would seem that the fish are sufficiently abundant for an ordinarily equipped fishing-smack, with its miles of trawls, to secure a full fare in a very short time.

The tile-fish, since the mortality of 1882, has been taken only along the edge of the continental plateau, in water near the one-hundred fathom line, from points south of No Man's Land, Block Island and the eastern portion of Long Island. The "range" of the species, as at present determined, is restricted to a tract of the sea bottom about one hundred and fifty miles in length, and ten to fifteen miles in width. The "stations," however, are few, and further investigation may result in a considerable extension of the range. The fish that have been caught during the past summer differ in respect to size from those that were caught before the mortality; for, while many are large, weighing fully twenty pounds, there are also many small immature individuals which often weigh but a pound or two. This percentage of immature fish would seem to indicate that the present environmental conditions are favorable, and that the species has become re-established.

H. C. Bumpus,

Director of Biological Laboratory.

U. S. F. C. Station, Woods Holl.

Note.—The "Grampus" again visited the tile-fish grounds the latter part of September, returning to Woods Holl on October 2, with over two hundred fish, weighing upwards of 3,000 pounds. This last catch was made between the meridians of 69 and 70, a

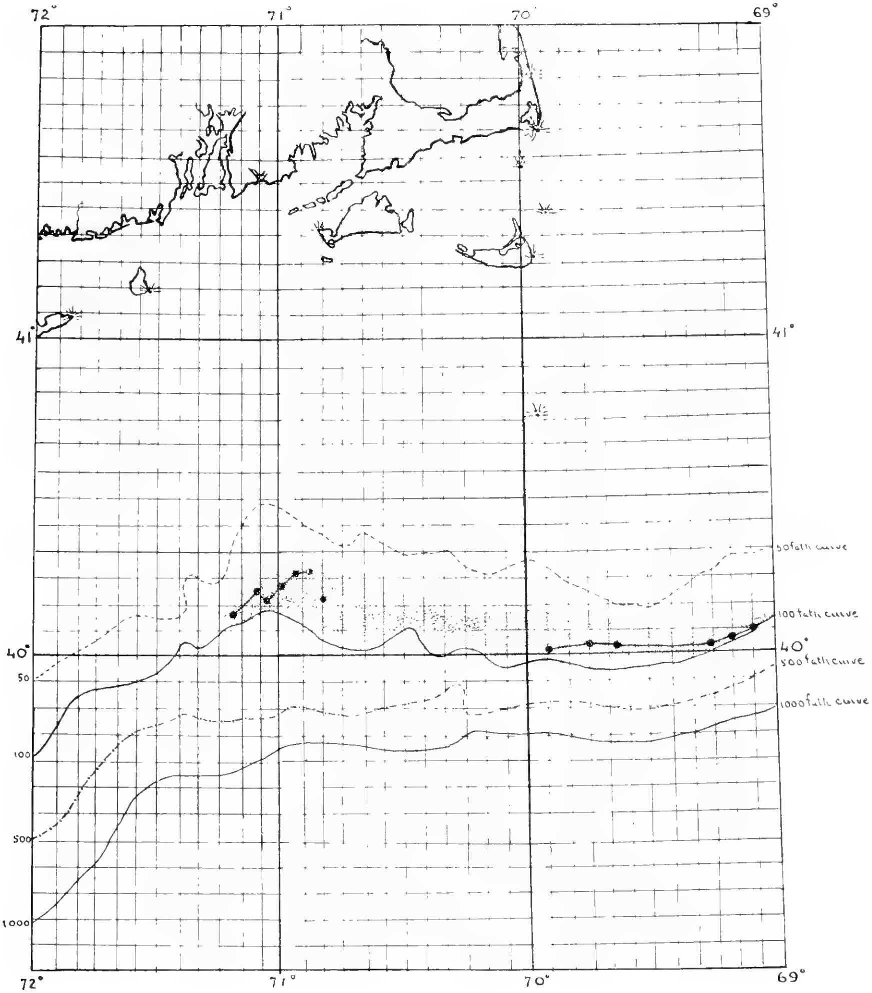


Chart showing the location of the tile-fish grounds. The stations at which tile-fish were actually taken are represented by heavy black dots connected with lines. The area of the sea bottom that is probably inhabited by the tile-fish is stippled.

tract that has not heretofore been known to be occupied by the fish, and indicates an eastern extension of the range of about twenty-five miles.—H. C. B.

XIII. *Improvements in the methods of preparing fish for shipment.*

The value of the fish caught along the shores of the State does not alone lie in their use as food by people residing within the limits of Rhode Island, but their exportation brings a large income to those interested in the industry.

A most casual examination of the methods of packing and shipping fish, when compared with the methods of packing and shipping poultry, meat, etc., will show that, whereas the methods of shipping the latter have materially improved within the last few years, the packing and shipping of fish is at the present time both crude and wasteful. The ice is in itself expensive; it occupies room that might be used for other purposes; its weight gives rise to excessive express charges; and when melted the fish are soaked in the impure fluid, and rendered unpleasant to handle, uninviting to witness, and subject to rapid decay.

Your Commission therefore has thought it advisable to examine more carefully into the present methods of packing and shipping fish, with the purpose of devising, if possible, some means which will eliminate many of the present unpleasant features. Mr. Ralph W. Tower was engaged to do this work, and his report is as follows:

SPECIAL REPORT

ON

METHODS OF PREPARING FISH FOR MARKET.

BY PROFESSOR RALPH W. TOWER.

It is a well known fact that ice, as it is used in the ordinary methods of fish packing, is more or less of a failure. It spoils the freshness, flavor, and firmness of the fish; but, more than this, the moisture of the melting ice favors the development of putrefactive bacteria and hastens decay. The investigations which I have made at the suggestion of the Commission have been planned for the purpose of ascertaining just how far fish are spoiled by carelessness, filth, and bad packing, and to devise methods of mitigating these evils.

Decay is nothing but the result of the activities of certain putrefactive bacteria. If the fish are so handled that the activity of the bacteria is restricted, the process of decay will be retarded; but if the fish are handled in such a way as to encourage the ravages of the bacteria, the process of decay will progress much more rapidly. The pressing of fish by close packing softens the muscles and renders the flesh more susceptible to invasion by putrefactive bacteria. Another item of no small importance is the packing of fish in foul barrels and unclean boxes, the contamination from which is conveyed to the several fish by the melting ice.

The animals used for the following experiments were squeteague,

bonito, bluefish, and tile-fish. The fish taken from the traps of the United States Fish Commission furnished an unlimited supply of material. During the months of July and August, the most abundant fish were squeteague. The flesh of these fish is soft, very susceptible to invasion by putrefactive bacteria, and difficult to preserve by the ordinary methods of packing. The flesh of the bonito is firm and hard, and is much easier to preserve.

I. The first experiments were made with squeteague, with a view to determining the influence of ordinary summer temperatures, and of different methods of killing and handling, upon putrefaction. Forty-eight fish were hung up, by a wire passing through the eyes. Twenty-four had the intestines removed, and the fish were drained immediately after capture. The remaining twenty-four were not opened. The experiment was made in a place that was protected from the sun, but to which the air had free access. The weather was humid and foggy, the temperature being 68° at 8 A. M., 72° at M., and 71° at 5 P. M. After remaining twenty-four hours, the fish were examined: those which were unopened were putrid and emitted an almost unbearable odor. The fish whose intestines had been removed were in a better condition, and the abdominal cavity was much fresher. Putrefaction had not penetrated so deeply into the flesh, and these fish might even have been used for food. The experiment shows that when the intestines are not removed decomposition takes place much more rapidly, and that the immediate removal of the viscera delays decomposition.

II. The next experiment was made with twenty-four squeteague and six bonitos. After the removal of the intestines as above the fish were laid on their sides, but not in contact with one another. The day was humid and foggy, the temperature ranging from 69° at 8 A. M., and 72° at 12 M., to 71° at 5 P. M. At the end of twenty-four hours the fish were examined. The squeteague were badly decomposed on the side next the wood. On the other side decomposition had not proceeded so far, although it had progressed to a considerable extent. In the body cavity decom-

position was evident, but it had not advanced very far. The bonitos were in much better condition, although an odor of putrefaction was noticeable, and the side on which they lay was most affected. The walls of the body cavity were also in better condition than those of the squeteague. The experiment showed that free circulation of air around fish retards decay.

III. After the intestines had been removed from twelve squeteague, the fish were hung up by their tails, and allowed to remain twenty-four hours. The weather was cloudy, and the temperatures were as follows: 8 A. M., 71°; 12 M., 74°; and 5 P. M., 73°. The atmospheric conditions were less favorable for the preservation of fish than on the previous day, yet at the end of twenty-four hours the fish were found to be in much better condition than in any of the preceding experiments. There was a decided odor of putrefaction on the outside of the fish, but the abdominal cavity and the muscles showed only a little evidence of decomposition. The fish were in as good condition as many fish found in our markets and generally sold as "fresh." The experiment shows that early cleaning, thorough draining, and free circulation of air retard putrefactive processes.

IV. Twenty-four living squeteague were decapitated, and their intestines removed. The intestines were removed from another series of equal number, but these animals were not decapitated. The forty-eight fish were then packed in a box, in close contact with one another. The weather and temperature conditions were practically the same as on the preceding day. At the end of twenty-four hours, the fish were examined. They were very soft and had a bad odor, although those which had been decapitated were in a better state of preservation than the others; all were unfit for use. The fish on the top layer, where they were exposed to the air, were in early, while those at the bottom, away from the air, and moistened by the drip from those above, were in advanced, stages of decomposition.—The experiment indicates the importance of thorough drainage of the flesh by early decapitation.

In all the above experiments the fish were taken from the fish-

trap alive, and were immediately prepared to meet the conditions of the various experiments. By this means no decomposition could have taken place before the experiments were begun. The fish were handled *as carefully as practicable*, so as to prevent bruising or rupture of the muscular tissue. Cleanliness was assured through copious washing with sea water.

To recapitulate, the experiments show that putrefaction takes place most rapidly in fish from which the intestines have not been removed; that moisture augments the process of decay. Free access of air tends to arrest, rather than promote, putrefaction, and drainage of the blood system is an important means of preventing decay. If the head and intestines are both removed, and the fish is suspended by the tail so that the blood, which is a most favorable medium for the growth of putrefactive bacteria, is drained from the entire body, the fish will remain sweet for a considerable time without the use of ice.

In none of the above preparations were putrefactive bacteria *prevented from entering the flesh*, or hindered in their action after entrance. Consequently further investigations were made to attempt to dress and pack the fish in such a manner that the bacterial invasion could be *delayed* at least for a few hours. To do this the fish were *washed* with a solution which would be unfavorable to the growth of bacteria, and at the same time not in any way injurious to the flesh. It is to be noted, however, that the fish are not injected with the solution, nor are they in any sense preserved in it.

Various solutions were tried, and, with one exception, without success. In every case the control experiments were made on fish taken at the same time, but not subjected to special treatment:

I. The first experiment was with a 0.1 per cent. solution of salicylic acid in sea water. Twenty-four squeteague, taken alive from the nets, were carefully dressed, washed with this solution, packed in a box, and allowed to remain for twenty-four hours. The temperature ranged from 73° to 76°. When examined the next morning, there was a perceptible odor of putrefaction; the

fish were soft and unfit for market. The control fish were not much worse. Experiments were subsequently made with the same solution, but none was successful.

II. The next preparation experimented with was a 10 per cent. solution of potassium nitrate. Eighteen squeteague, cleaned immediately after being taken from the nets, were decapitated and thoroughly washed with this solution, and packed close together in a box. During the next twenty-four hours the weather was foggy, and the temperature ranged from 73° to 74°, at the end of which time decomposition had advanced to such a stage that the fish were totally unfit for market. There was no appreciable difference between the fish subjected to the potassium nitrate and those of the control experiment. Six more trials were made with this solution, but always with the same results.

III. A 5 per cent. solution of formalin was next used, but, as might have been predicted, the fish did not keep, and they were as bad at the end of twenty-four hours as those of the control.

IV. The next, and most successful, experiment was made with a 3 per cent. solution of boric acid (B_2 O_3) in sea water. Two dozen squeteague were dressed immediately after being caught. Some were decapitated, and others were packed with head and gills attached. All were then *merely washed* in the above solution, and then closely packed in a box. The weather was foggy and cloudy. The temperature ranged from 74° to 83°. When examined, twenty-four hours later, the fish were found to have kept well. There was no odor, and decomposition had evidently not begun. The flesh was hard and firm, the eyes were clear, and in fact one of the fish was declared, by a native fisherman, to have been taken from the water that very morning, and he was not readily convinced that it had been kept without ice for twenty-four hours. One of these squeteague was baked and served on my own table, and was pronounced excellent. It is needless to say that the control fish were in advanced stages of putrefaction, and wholly unsuitable for food.

In these experiments with boracic acid, the fish were in no sense

"embalmed," or even preserved. The walls of the adominal cavity, after the removal of the viscera, were simply washed with a sponge that had been dipped in the solution. The success of the experiment is of course largely dependent upon the *immediate removal* of the viscera after the capture of the fish; the *careful handling* of the fish, both before and after evisceration; the thoroughness with which the walls of the abdomen are washed; and the care with which the fish are packed. The use of boric acid will not prove satisfactory if fish are first thrown about, walked upon, slovenly eviscerated, washed in the sterilizing fluid, and then pitched into barrels. Those who prefer to abuse fish in this way will do well to stand by the older and more expensive methods, use ice, and complain of the market.

Mr. Eugene G. Blackford, one of the largest wholesale dealers in New York, has said, "As an example of the increased returns to the shippers from careful handling, I call attention to the fact that certain shipments of shad, going to the New York market from North Carolina, bring from 25 per cent. to 40 per cent. more than other shad from the same locality."

"What I wish to impress upon the shippers and fishermen is, that for every dollar invested in labor and ice in packing the fish they will receive ten dollars in return."

Twenty more experiments were made with the same solution. Some of the animals were decapitated and others were not, but the swim-bladders and kidneys were removed from all. If the gills were thoroughly washed in the solution, it was found that even fish with the head attached kept as well as those which were decapitated. Nevertheless, in fish treated with boric acid, it is in the gills that putrefaction first shows itself.

A bushel basket full of squeteague prepared in this way was put on the deck of the U. S. F. C. S. Grampus, on the morning of August 12, where they remained exposed to the sun throughout the day. The next morning, when they were cut up for bait, they showed no sign of decomposition. On another trip, a catch of tile-fish weighing 1,000 pounds was washed in the solution. The

fish were then packed in ice, where they remained for two weeks. When unpacked they were in a *perfectly fresh* condition.

It is evident, then, that this solution retards the initial stages of putrefaction, even at summer temperatures, and for a sufficient time for the fish to arrive at the markets, where they may be iced and kept indefinitely. The solution of boric acid thus used is *not a preservative*, and it is not intended as such, but, like soap, is an *agent of cleanliness*. As the fish are simply sponged over, the amount of the fluid that remains on a single fish is inconsiderable, and careful analysis fails to show more than the least trace in the flesh. Moreover, Chittenden and Gies have shown that boric acid given in doses, even up to 3 gm. per day, has no effect upon proteid metabolism, or on the nutrition of the body; that it is not cumulative, but is quickly eliminated from the system; and that it produces no renal complications. Its employment, therefore, as above recommended, can have no injurious effect on the consumer.

In preventing the growth of the micro-organisms which cause putrefaction we also eliminate the cause of ptomaïne formation. Though some of the ptomaïnes are exceedingly poisonous, this is not characteristic of all, and it can be safely stated that the greater number of those that have been isolated are of a non-poisonous nature. The kind of ptomaïn that is formed depends upon the sort of micro-organism which produces it, the character of the material acted upon, and the circumstances under which putrefaction takes place. As the ptomaïnes are only transition products in the process of putrefaction—mere temporary stages in the great process of decomposition by which the complex organic molecule is transformed into the simple inorganic state—it is evident that the kind of ptomaïn present in putrid fish is dependent upon the stage of putrefaction. The ptomaïnes formed when the putrefaction takes place in free atmosphere will also be different from those resulting from putrefaction where atmosphere is excluded. At the present time almost any illness caused from infected food is generally spoken of as being due to "ptomaïn poisoning." In the majority

of cases, however, the poisonous bacterial products are not basic, although their true chemical structure is not understood.

The researches of Meisener Rosenbach, G. Hauser, F. John J. von Todor, and others, have shown that the blood and flesh of healthy animals is entirely free from bacteria. But the contents of the digestive organs are rich in Schizomycetes. (Popoff has shown that the digestive canal of a healthy new-born animal is, at the moment of birth, free from bacteria. These, however, subsequently obtain access, principally in the food, and the contents of the bowels become extremely rich in microbes.)

If a slaughtered animal is left without being disemboweled, these bacteria will make their way through the capillary vessels of the intestinal villi into the arterioles, the alkaline contents of which (rich in albumen) are especially favorable to these acidly putrefactive bacteria, so that the entire carcass quickly begins to undergo decomposition. This early decay may be prevented by the immediate removal of the entire alimentary canal, from œsophagus to rectum, and, if this precaution be taken, the flesh will for a time remain free from putrefactive bacteria. If putrefaction afterwards sets in, it is due to the bacteria from external sources obtaining access to the flesh.

The gradual penetration by way of the blood vessels into the interior of the flesh has been studied by Trombetta and Gartner. Gartner found them only in the external layers of meat three days old; but at the end of seven days they had penetrated 2 c. c. below the surface. It is, however, probable that the flesh of fish is not so resistant to the penetration of bacteria. The sources of this bacterial infection cannot be entirely removed, but they can be considerably reduced by cleanly procedure, and attempts may be made to restrict the increase of the microbes and thus arrest the process of decay. The most common remedy is cold, but experiment has shown that the temperature must be kept some degrees below zero C. in order to obtain the best results. This method is used not only in the American and Australian abattoirs, but haddock caught in Norway are cleaned and frozen at 50° C,

and are then shipped in specially constructed steamers. This freezing of the fish does not immediately kill the bacteria present, but prevents their reproduction for the time being. Koch has found very many bacteria in fish that have been treated in this way. Foster has found that certain germs increase in meat stored at moderately low temperatures, though actual putrefaction is not produced by them. Moreover, the researches of Frænkel, Bordoin, Uffreduzzi, Prudden, and Heyroth show us that natural ice may contain both putrefactive and pathogenic bacteria. This fact alone should teach us to look with suspicion upon any meat that has been brought in direct contact with ice, especially where the ice is allowed to melt and the drip to permeate the flesh.

It is worthy of note in this connection that poisonous ptomaïnes do not begin to appear until about the seventh day of putrefaction, and that they finally disappear, if putrefaction is allowed to go on for a considerable time. The toxicity of the ptomaïnes themselves is not affected by cooking, no matter how thorough this may be. There are two distinct kinds of poisoning that may arise from the use of fish as food. The first is an intoxication caused by the devouring of meat which has become invaded by ptomaïn-producing bacteria. The second is an intoxication brought about by fish not necessarily infected with bacteria, but in which the poisons are *leucomaines* produced by the tissues of the fish and their normal product, in the same way that certain toad-stools are always poisonous.